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DIVISION OF STRUCTURES AND ENGINEERING SERVICES

TRANSPORTATION LABORATORY

RESEARCH REPORT

Vehicular Crash Tests Of Unanchored Safety-Shaped Precast Concrete Median Barriers With Pinned End Connections

FINAL REPORT

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Prepared in Cooperation with the U.S. Department of Transportation, Federal Highway Administration

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CALIFORNIA DEPARTMENT OF TRANSPORTATION

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This study was conducted in cooperation with the U. S. Department of Transportation, Federal Highway Administration for the project titled, "Tests of the Stability of Precast, Safety-Shaped Concrete Median Barrier".

16. ABSTRACT

Four vehicular crash tests of three different unanchored precast concrete median barrier (CMB) designs with pinned end connections are reported. Large size passenger cars weighing about 4900 lbs impacted the barriers at speeds/angles of 65 mph/7°, 68 mph/23°, 66 mph/40°, and 39 mph/25°. Barrier tilting and excessive lateral barrier movement contributed to vehicle vaulting and hazardous vehicle trajectories in two tests. The barriers for these same two tests were extensively damaged. Vehicles were redirected in two moderate impact tests. Based on the results of the four crash tests and a limited field survey, recommendations restricting the use of precast CMB segments with pinned end connections for temporary and permanent barrier installations and stressing the need for tighter barrier joints to minimize lateral and rotational barrier movement are included. Further research is suggested.

17. KEY WORDS

Barriers, deceleration, dynamic tests, impact tests, median barriers, precast concrete, vehicle dynamics.

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DEPARTMENT OF TRANSPORTATION
DIVISION OF STRUCTURES & ENGINEERING SERVICES
OFFICE OF TRANSPORTATION LABORATORY

August 1976
TL No. 636624
Item No. D-4-107

Mr. C. E. Forbes
Chief Engineer

Dear Sir:

I have approved and now submit for your information this final research project report titled:

VEHICULAR CRASH TESTS
OF UNANCHORED SAFETY-SHAPED
PRECAST CONCRETE MEDIAN BARRIERS
WITH PINNED END CONNECTIONS

Study made by . . . . Structural Materials Branch

Under the Supervision of. . . . . E. F. Nordlin, P. E.

Principal Investigator. . . . . J. R. Stoker, P. E.

Co-Principal Investigator . . . . R. L. Stoughton, P. E.

Co-Investigator . . . . D. M. Parks, P. E.

Report Prepared by . . . . R. L. Stoughton, P. E.
and
D. M. Parks, P. E.

Very truly yours,

George A Hill

GEORGE A. HILL
Chief, Office of Transportation Laboratory

RLS/DMP:bjs
Attachment

ACKNOWLEDGEMENTS

This work was accomplished in cooperation with the United States Department of Transportation, Federal Highway Administration, Item D-4-107 of Work Program HPR-1(12), Part 2 Research titled "Tests of the Stability of Precast, Safety-Shaped Concrete Median Barrier".

The contents of this report reflect the views of the Transportation Laboratory which is responsible for the facts and the accuracy of the data presented herein. The contents of this report do not necessarily reflect the official views or policies of the State of California or the Federal Highway Administration. This report does not constitute a standard, specification or regulation. It should also be recognized that the opinions, findings, and conclusions expressed in this publication are not necessarily those of the Federal Highway Administration.

Special appreciation is due the following staff members of the Transportation Laboratory who were instrumental in the successful completion of these tests and in the preparation of this report:

Lee Staus	In charge of preparation and operation of the test vehicles and other test equipment, and preparation of test barrier plans and specifications.
Jim Keesling	In charge of photo and electronic instrumentation data reduction, and preparation of the movie report.

Roger Pelkey Orvis Box Bill Crozier Vince Martin Lee Wilson	Assisted with test preparation, tests, data reduction, or preparation of the final report.
Robert Mortensen Lewis Green Kerry Wilson	Data and documentary photography
Richard Johnson Delmar Gans Stanley Law	Electronic instrumentation of the test barriers, vehicles and dummy.
Marion Ivester Elmer Wigginton	Drafting of barrier plans, tables, figures, and instrumentation data traces.
Larry Stevens	Reproduction

Appreciation is also due the following personnel from the California Department of Transportation who were available for technical consultation and advice during the project:

Ed Tye Dick Smith Bill Juergens	Office of Traffic
Ralph Bishop Phillip Hale, Jr.	Office of Structures Planning
Ray Hackett	Office of Structures Operations
John Evans	Value Engineering

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INTRODUCTION

Use of the California Concrete Barrier Type 50, which employs a safety-shaped ("New Jersey") profile, as a permanent median barrier has increased rapidly since 1971. This median barrier was approved for use in California after conducting successful vehicular crash tests on a prototype design in 1967(1), and after evaluating an experimental in-service barrier installation between 1968 and 1970. The final report on the in-service barrier was completed in November, 1970(2), and the new concrete median barrier (CMB) design was shown in a California Traffic Manual revision published in December, 1970(3). Since that time over 300 miles of CMB have been installed in California.

By 1971 some states were using a string of precast concrete segments with the safety shape as median barriers. About that time the California Department of Transportation (Caltrans) became interested in precast CMB segments for use as temporary median barriers on metropolitan freeway construction projects. A median barrier that could easily be relocated for each temporary detour change was needed to separate opposing lanes of traffic. Previously a movable double Metal Beam Barrier design was used for these temporary detour changes. Considerable time and labor were required everytime this barrier was relocated. In contrast, portable precast concrete barrier segments could easily be installed or relocated with a minimum of traffic delay. Precast barrier segments damaged during vehicle accidents could also be easily removed. In addition, their potential reuse as a permanent barrier was an attractive possibility.

At the time this research project was initiated, no vehicular crash tests had ever been conducted on CMB composed of individually connected precast concrete barrier segments. Also, in the states where precast CMB was being used (Idaho, Missouri, Ohio, Oregon, Washington, and the Province of British Columbia) operational experience was limited and very little accident experience had been documented. Based on a review of the precast CMB designs already in use, a design with pinned end connections was selected for the first two vehicular crash tests conducted by Caltrans, Tests 291 and 292. The steel rod connection was chosen over a formed concrete tongue and groove shear key design used by the State of Oregon. The reasons for the choice at that time were as follows:

- The pinned ends would provide some continuity across the joints between adjacent precast CMB segments.

- A limit on possible lateral barrier movement would be achieved by the positive link between the precast CMB segments.

- The pinned ends would allow some extra joint flexibility so that the end lengths of barrier segments could be flared away from traffic at construction sites.

- Precast CMB segments with pinned end connections could be placed faster than the barriers with shear keys and the pinned end design was also easier to install on uneven ground.

- Damaged pinned end precast CMB segments could be easily replaced.

In this report the results of four vehicular crash tests of three different unanchored precast CMB designs with pinned end connections are described and discussed. In all of the trial designs the barrier segments were pinned together by placing steel rods through overlapping steel hinge bars cast in the ends of the segments. Both closed, 1/2 inch maximum gap between segments, and open, 2 3/4 inch maximum gap pinned joint designs, and barrier segment lengths of 12.5 feet and 20 feet were tested. All four tests were conducted between 1972 and 1974. It was hoped to find a precast CMB design acceptable for use both in temporary and permanent installations. The tests were conducted to evaluate the strength and stability of the test barrier designs during impact since the barrier cross-sectional geometry had been proven effective in previous tests.

Parameters for the tests were as follows:

Test No.	Segment Length, Feet/ Open or Closed Joint	Vehicle Weight Lbs.	Impact Velocity mph	Impact Angle, Deg.
291	12.5/closed	4860	65	7
292	12.5/closed	4860	68	23
293	20/open	4860	66	40
294	20/closed	4700	39	25

During the time period when these vehicular crash tests were conducted, Caltrans was also using an alternative design for temporary use at construction sites. Precast CMB segments 20 feet long were chained together. Two turns of 3/8 inch chain passed through holes near the ends of the unanchored segments. The chains were recessed in shallow grooves formed into the sides of the barrier segments to prevent the chains from sticking out where they could be snagged. This barrier has been used extensively for bridge falsework protection during construction. Comments on the chained precast CMB and various pinned end precast CMB designs used by construction personnel in California are discussed in the Appendix of this report.

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

The following conclusions were based on the results of four vehicular crash tests conducted to determine the structural strength and stability of three different unanchored reinforced precast CMB barrier designs on asphalt concrete (AC) pavement. The barrier segments were either 12.5 feet or 20 feet long. Designs with either closed or open pinned joints having maximum gaps between adjacent barrier segments of 1/2 inch or 2 3/4 inches respectively were tested. The barrier segments were connected together by placing steel rods through two pairs (one pair at the end of each segment) of overlapping steel hinge bars cast in the ends of the barrier segments.

1. Severe Impact Conditions. The three unanchored reinforced precast CMB designs with pinned end connections tested by Caltrans failed to meet the structural adequacy and vehicle trajectory hazard criteria outlined in NCHRP Report 153(4) for the reasons outlined below. The barriers were subjected to strength test conditions of vehicle weight/impact speed/impact angle of 4860 lbs/68 mph/23° for Test 292, 4860 lbs/66 mph/40° for Test 293, and 4700 lbs/39 mph/25° for Test 294:

- Barrier Tilting. None of the designs resisted barrier tilting during impact. This tilting caused vehicle vaulting and uncontrolled vehicle trajectories in two tests.

- Lateral Barrier Movement. None of the designs prevented lateral barrier movement which was excessive in two tests and also contributed to erratic airborne vehicle trajectories. The average length of barrier segments having some lateral movement was 80 feet for the three tests.

• Barrier Damage. Two barrier designs were extensively damaged; the third design had minor concrete spalling at the joints which might have been more severe if the impact speed of 39 mph had been higher.

2. Moderate Impact Conditions. One of the three designs was subjected to a shallow angle test with impact conditions of 4860 lb vehicle/65 mph/7°, Test 291. In this test there was a limited amount of lateral barrier movement, 6 1/4 inch maximum, no perceptible barrier tilting, and minor concrete spalling.

In Test 294 with impact speed/angle of 39 mph/25° the barrier performance was judged unsatisfactory because of barrier tilting. The tilting caused a rather high climb of the vehicle upon the barrier, and a possibly hazardous vehicle trajectory. However, barrier and vehicle damage and lateral barrier movement were relatively slight. Therefore, had the impact conditions been slightly less severe, for example with a smaller angle of impact, this barrier design would have been judged satisfactory for moderate impact conditions.

In a limited survey of Caltrans Office of Construction personnel it was concluded that precast CMB, with pinned end connections similar to the test barriers, when used as a temporary barrier was generally effective in redirecting impacting vehicles with minor barrier translation. This field experience supports the effectiveness of the barrier for moderate impact conditions.

RECOMMENDATIONS

Temporary Uses of Precast CMB

Based on the results of crash tests described in this report and summarized in Table 1 (in the Discussion of Test Results section of this report), recommendations concerning the use of Temporary

Railing Type K specified in the 1975 California Standard Plans, Figure 17A in the Appendix, are as follows:

- Connection details should be modified to provide tighter joints between barrier segments to minimize lateral and rotational barrier movement, and to improve continuity across the barrier joints.

- Nuts and plate washers should be placed on the bottom of all connection rods as shown in the 1975 Standard Plans. These were added as a result of Test 293.

- Precast barrier segments similar to the designs tested should only be used at locations where impact conditions are expected to be in the moderate range of impact speed/angle of 40 mph/20° to 60 mph/13° based on site conditions such as posted speed limit, roadway width, flare angle of barrier installation, etc. This restriction assumes a maximum passenger vehicle weight of 4500 lbs with a corresponding maximum lateral component of kinetic energy for the vehicle at the time of impact of about 28,000 ft-lbs.

- Precast barrier segments used for the above moderate impact conditions should be placed at least 1 foot clear of any roadway excavation, cut line for bridge widenings, falsework, or any other objects being shielded.

- For impact locations where lateral impact kinetic energy is expected to exceed 28,000 ft-lbs, precast barrier segments should be anchored to the ground.

- Precast barrier installations should be at least 100 feet long (excluding special terminal barrier segments) at all locations. The precast barrier segments at each end of the installation should be firmly anchored to the ground so that they will not pivot if impacted.

Permanent Uses of Precast CMB

None of the three barrier designs tested should be used as permanent CMB installations without modifications to provide anchorage to the ground and more structural continuity at joints between the barrier segments.

Future Testing

1. Vehicular crash testing should continue on any new precast CMB designs for temporary and permanent uses which show promise of resisting more severe impact conditions than those barriers tested in this series. There is a need for temporary precast CMB with higher performance standards.

2. New designs should have improved structural continuity at joints and/or anchorage to resist lateral movement and tilting. However, these modifications should not be made entirely at the expense of ease of assembly and portability of barrier segments, and low cost of production.

IMPLEMENTATION

The Offices of Traffic, Structures, and Construction will review the findings and recommendations of this report to determine what changes in standard plan designs and use of unanchored precast CMB with pinned end connections are warranted.

TECHNICAL DISCUSSION

Test Conditions

1. Test Facility

All four vehicular crash tests were conducted on an AC runway, approximately 3 inches thick, at Lincoln Municipal Airport located about four miles from Lincoln, California.

2. Test Barriers - Design and Construction

Key structural elements and design features for each test barrier are shown in Figure 2 attached at the end of this section, Test Conditions. Complete details of the test barriers are contained in the Appendix, Figures 14A through 16A.

Barrier segments for Tests 291 and 292 were delivered to the test site by truck and placed in position by a small crane which was mounted on the rear of the delivery truck. The crane operator, standing on the ground, used remote controls to position each 12.5 foot long barrier segment, Figure 1. Two large tongs, hooked in small slots next to the scuppers, held the barrier segments during the placement operation. This method of placement was quick and easy.

Barrier segments for Tests 293 and 294 were delivered on flat bed trucks and placed with fork lifts. The forks were inserted in the scuppers for lifting the 20 foot long segments.

A summary of material sample tests of the strength of the concrete, embedded hinge bars, and connecting rods used in the test barriers is contained in the Appendix, Figure 18A.

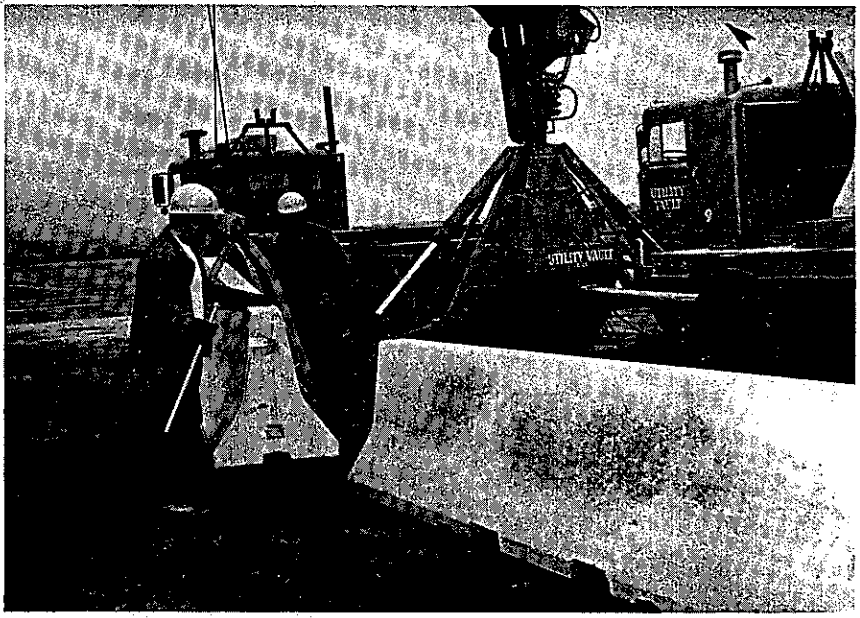


Figure 1, Placing 12.5 Foot Barrier Segments
With Truck Crane

3. Test Vehicles

The test vehicles for Tests 291, 292, and 293 were 1969 Dodge Polara sedans, each weighing 4860 lbs. For Test 294 a 1968 Dodge Polara sedan weighing 4700 lbs was used. All vehicles were in good condition, free of body damage and missing structural parts. The vehicle weights included on-board instrumentation, one dummy, and a gas tank filled with water.

All vehicles were self-propelled. Remote radio control in a follow vehicle was used to guide the test vehicle into the barrier in Tests 291 and 292. A cable guidance system was used in Tests 293 and 294. A short distance before the point of impact, the vehicle ignition was turned off in all tests. Remote brakes were applied in all tests after the vehicle had impacted the barrier and established a post impact trajectory.

4. Data Acquisition Systems

High speed and normal speed movie cameras and still cameras were used to record the impact events and the conditions of the vehicles and the barriers before and after impact.

An anthropometric dummy with accelerometers mounted in its chest and head cavities was placed in the driver's seat to obtain motion and deceleration data. The dummy, Sierra Stan, Model P/N 292-850, manufactured by Sierra Engineering Company, is a 50th percentile male weighing 165 lbs. The dummy was restrained by a standard lap belt during the tests.

Accelerometers were also mounted on the floorboard of the test vehicles. Deceleration data were collected to judge impact severity and to evaluate vehicle occupant injury tolerances.

Houston Position Transducers were used in Tests 293 and 294 to measure lateral movement and tilting of the first barrier segment impacted by the test vehicle.

The Appendix contains a detailed description of: the mechanical instrumentation in the test vehicles; photographic equipment and data collection techniques; electronic instrumentation and data reduction methods; and accelerometer records.

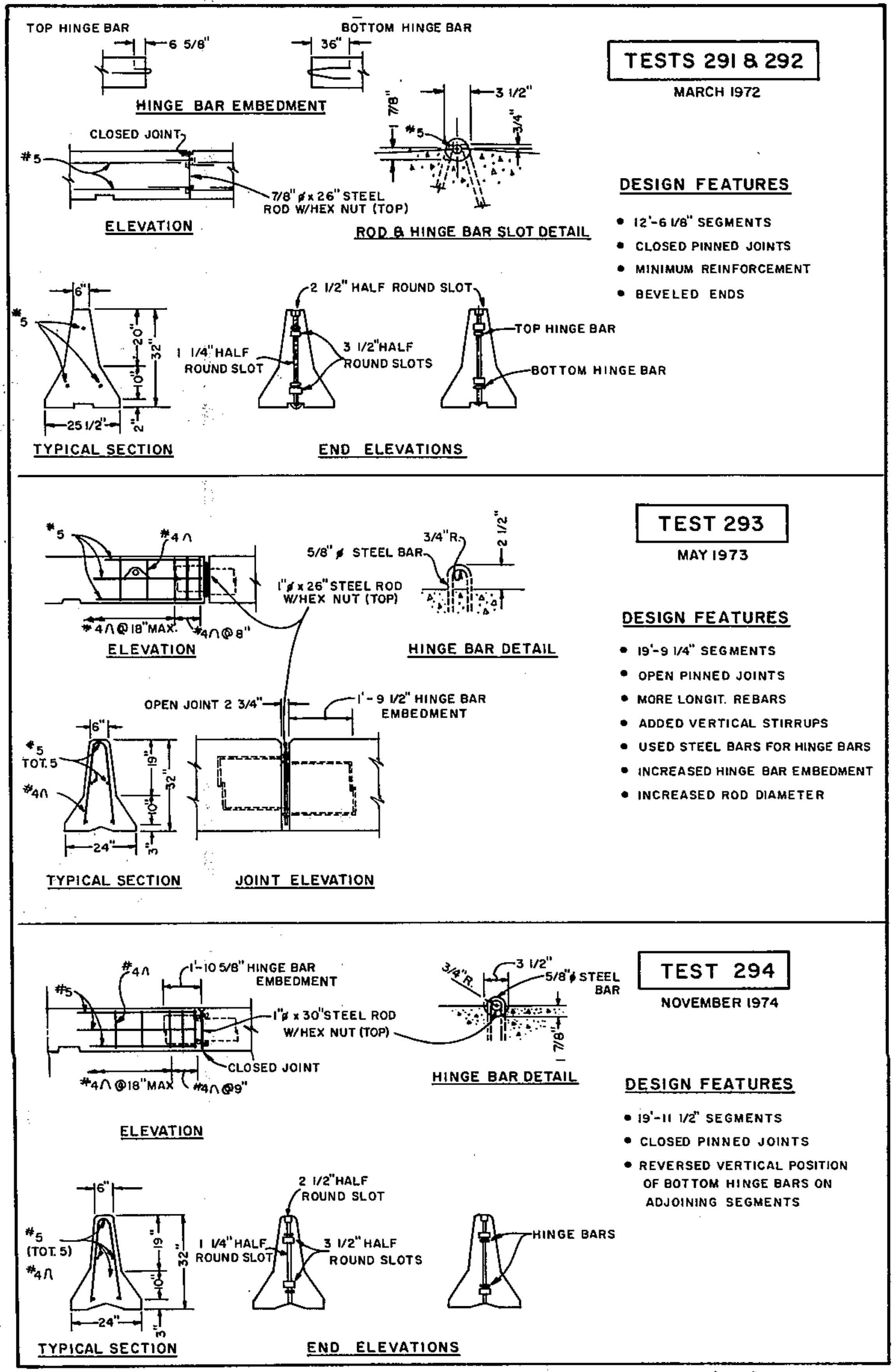


FIGURE 2, PRECAST MEDIAN BARRIER DESIGNS (1,2)

1. DETAILED PLANS IN APPENDIX
2. 1in = 25.4mm; 1ft. = 0.305m

Test Results

Key design features for each test barrier are shown in Figure 2. Detailed plans for the test barriers are included in the Appendix.

Attached at the end of this section of the report and referenced in the descriptions of the four tests which follow are the following figures and photographs: Data summary sheets for each test which include sequential impact photographs and vehicle trajectories, Figures 3 through 6; drawings showing permanent lateral displacement at each barrier joint, Figure 7; photographs of barrier movement, Figures 8 and 9; barrier damage photographs, Figures 10 through 22; and vehicle damage photographs, Figures 23 through 26.

A 17 minute color film report was assembled to summarize the four crash tests described in this report.

1. Test 291

Test Conditions - A 1969 Dodge Polara sedan weighing 4860 lbs impacted the precast concrete test barrier at 7° with a velocity of 65 mph. The fourth 12.5 foot long segment of the 150 foot test barrier was impacted 3.5 feet beyond its upstream end, Figure 7.

Impact Description - The vehicle was smoothly redirected. During impact the left side of the vehicle rode up along the face of the barrier. The vehicle rolled away from the barrier 18° and exited parallel to the barrier at a velocity of 54 mph. During redirection, the vehicle remained in contact with three barrier segments, a total distance of 30.5 feet, and rose to a maximum height of 2.3 feet.

Barrier Movement and Damage - Maximum lateral barrier displacement of 6 1/4 inches occurred at the first pinned barrier joint downstream from the point of impact, Figures 7 and 8. Five of the twelve barrier segments translated laterally during impact.

The barrier suffered minimal damage from impact. However, there was some minor concrete spalling at the bottom front face of the first joint downstream from impact due to local closing of the joint in compression.

Vehicle Damage - Vehicle damage was also minimal, Figure 23. There were some minor dents and scratches on the left front and rear quarter panels of the vehicle. This same vehicle was used for a second impact test, Test 292, later the same day without being repaired. There was no intrusion of vehicle or barrier parts into the passenger compartment during impact.

Dummy Behavior - Upon impact, the dummy, restrained by a lap belt, hit the left front door and steering wheel of the vehicle. The dummy was found slumped against the left door after the test. Dummy accelerometer and lap belt load data are included in the Appendix, Figures 8A and 12A.

2. Test 292

Test Conditions - The barrier segments which were realigned and the vehicle which was unrepaired after Test 291 were reused for this test.

The 1969 Dodge Polara sedan impacted the precast concrete test barrier at 23° with a velocity of 68 mph. The sixth segment of the test barrier was impacted 1 foot beyond its upstream end, Figure 7.

Impact Description - Upon impact, the barrier segment initially impacted was fractured, moved laterally, and started to tip back off line as the test vehicle rode up its sloped face. The vehicle continued to climb, using the tipped barrier segment as a ramp, and became airborne while being redirected parallel to the barrier. Along an airborne trajectory path of about 56 feet, the vehicle's left front tire reached a maximum height of 7.0 feet with the vehicle rolling clockwise 61° away from the barrier. During descent, the vehicle yawed clockwise becoming nearly perpendicular to the centerline of the barrier before recontacting the barrier near the last joint. The vehicle slid along the top of the last barrier segment and returned to the ground almost perpendicular to the centerline of the barrier and about 28 feet downstream from the last barrier segment.

Barrier Movement and Damage - Six barrier segments were laterally displaced during impact, Figures 7 and 8. Maximum lateral displacement of 22 1/4 inches occurred at the upstream end of the first impacted barrier segment, joint 5. The downstream end of this segment moved laterally 16 1/4 inches. All of the pinned joints of the barrier remained connected during impact. During impact, the initially impacted barrier segment leaned back about 16° away from its vertical axis.

The test barrier suffered considerable damage. At the point of impact the barrier failed in bending. The tension side of the barrier was completely fractured, while the front face of the barrier showed signs of a severe compression failure, Figure 10.

The top reinforcing steel hinge bar at the first downstream barrier joint from impact, joint 6, was pulled out of the concrete, Figure 11. A crack in a barrier segment at joint 7 also indicated a probable bond failure of a top reinforicng hinge bar, Figure 12.

In addition to the fractured concrete at the locations of impact and pull-out of two top hinge bars, concrete spalled at joints 4, 5, and 6, Figures 13 through 15. Several large spalled pieces of concrete, 10 inches maximum dimension, were thrown about 25 feet in back of the barrier during impact. The steel rods connecting joints 4 through 7 were bent during impact.

Vehicle Damage - The left side of the test vehicle suffered extensive damage during impact with the precast barrier segments, Figure 24. There was no intrusion of vehicle or barrier parts into the passenger compartment during impact.

Dummy Behavior - Due to a camera malfunction, high speed film coverage of the lap belted dummy was not available for analysis. However, dummy accelerometer and lap belt load data are included in the Appendix, Figures 9A and 12A.

3. Test 293

Test Conditions - A 1969 Dodge Polara sedan weighing 4860 lbs impacted the precast concrete test barrier at 40° with a velocity of 66 mph. A malfunction of the cable guidance bracket causing vehicle yawing prior to impact, prevented the vehicle from attaining an anticipated impact angle of 25°. The third 20 foot long segment of the 100 foot test barrier was impacted 1 foot beyond its upstream end, Figure 7.

Impact Description - Upon impact, the barrier segment initially impacted was moved laterally and pushed over backwards as the test vehicle rode up its sloped face. The vehicle continued to soar, traveling behind the test barrier, and reached a maximum airborne height (left rear tire) of 7.1 feet while rolling clockwise 33° away from the barrier. While airborne for about 60 feet, the test vehicle yawed clockwise passing over the last two barrier segments and hit the ground nearly perpendicular to the centerline of the barrier 20 feet downstream from the end of the barrier. The vehicle rolled over once and stopped 60 feet downstream and 26 feet in back of the test barrier.

Barrier Movement and Damage - Four of five barrier segments were laterally displaced during impact, Figures 7 and 9. Only the last barrier segment remained on line. Maximum lateral displacement of 11 1/8 inches occurred at the upstream joint of the first impacted barrier segment, joint 2, Figure 7. The second and third joints failed to restrain the lateral and rotational movement of the impacted barrier segment, which tipped over on its side. The steel hinge bars and steel connecting rods were severely bent, Figure 16. The steel rod at joint 1 was also bent during impact, Figure 17.

Concrete spalling also occurred at joints 2 and 3, Figure 18.

Vehicle Damage - The test vehicle was severely damaged from the barrier impact and post impact rollover, Figure 25. The engine intruded about 3 inches into the passenger compartment of the vehicle during impact.

Dummy Behavior - Upon impact, the dummy, restrained by a lap belt, slumped towards the passenger's side and moved forward under the dashboard of the vehicle. As the vehicle descended from its airborne trajectory and hit the ground, the dummy impacted the steering wheel and the left front wing window. As the vehicle rolled over, the dummy's head protruded out the front door window and impacted the ground. When the top of the vehicle caved in during the vehicle rollover, the dummy's right arm and shoulder were crushed. After impact, the dummy was found slumped against the left door. Dummy accelerometer and lap belt load data are included in the Appendix, Figures 10A and 12A.

4. Test 294

Test Conditions - A 1968 Dodge Polara sedan weighing 4700 lbs impacted the precast concrete test barrier at 25° with a velocity of 39 mph. A premature ignition failure prevented the vehicle from reaching an anticipated impact velocity of 60 mph. The fourth 20 foot long segment of the 120 foot test barrier was impacted 10.8 feet beyond its upstream end, Figure 7.

Impact Description - The vehicle was smoothly redirected. Upon impact, the left side of the test vehicle rode up the face of the barrier, reaching the top edge 10 feet after initial barrier contact. As the barrier segment tipped back off line 6°, the vehicle travelled 24.5 feet along the top edge of the barrier, and exited at 4° and 30 mph. During redirection, the vehicle rolled 33° away from the barrier, became airborne for about 16 feet while travelling along the top of the barrier, and remained in contact with the barrier for 36.5 feet. After exiting momentarily at 4°, the vehicle yawed clockwise, arcing away from the front of the barrier and stopped 46 feet downstream and 70 feet perpendicular to the line of the face of the barrier after the remote brakes were applied.

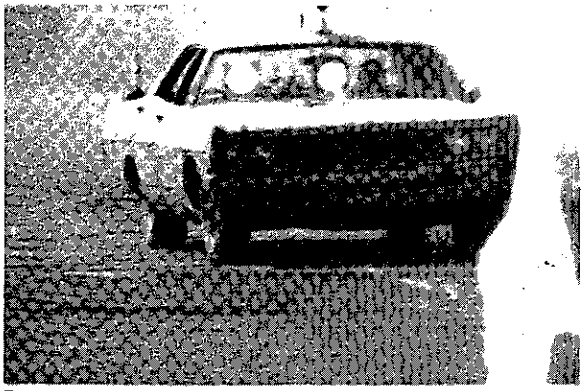
Barrier Movement and Damage - Four of six barrier segments were laterally displaced during impact, Figures 7 and 9. Maximum lateral displacement of 5 1/2 inches occurred at the first barrier joint downstream from impact.

The test barrier suffered no structural damage other than some concrete spalling at the second, third and fourth barrier joints, Figures 19 through 21. Also, there were scrapes and tire scuff marks on the front face of the barrier, Figure 22.

Vehicle Damage - The front left quarter section of the vehicle was moderately damaged during impact, Figure 26. The front bumper was pushed about 1.3 feet back away from its original plane. There was no intrusion of vehicle or barrier parts into the passenger compartment during impact.

Dummy Behavior - Upon impact, the dummy, restrained by a lap belt, hit the left front door and then slumped towards the passenger's side as the vehicle started to roll. As the vehicle hit the ground, the dummy hit its head on the headliner above the left front door. After impact, the dummy was found slumped against the left door. Dummy accelerometer and lap belt load data are included in the Appendix, Figures 11A and 12A.

Figure 3, DATA SUMMARY SHEET



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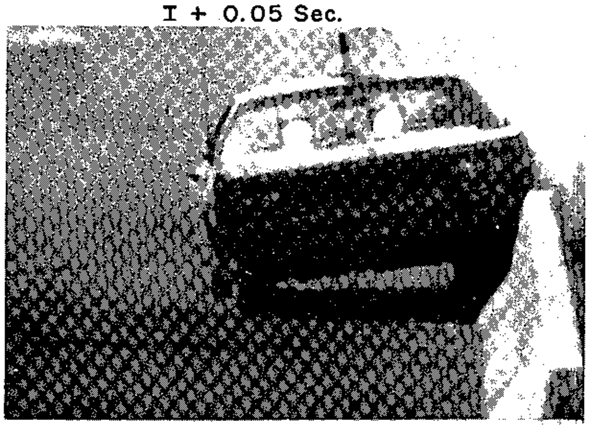

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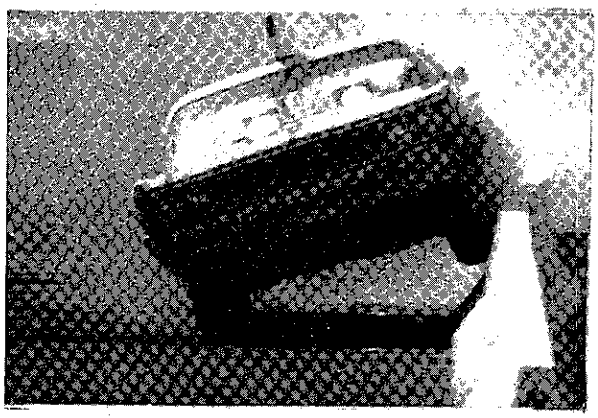

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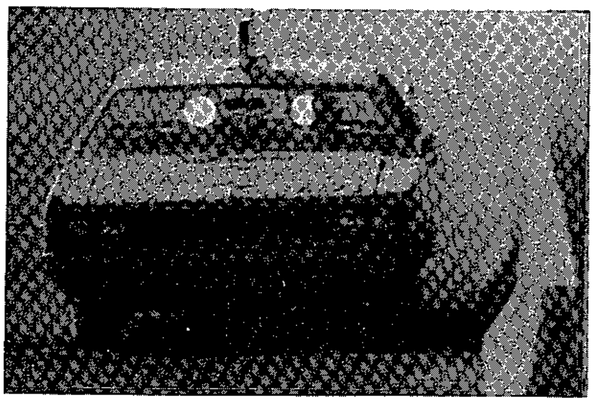

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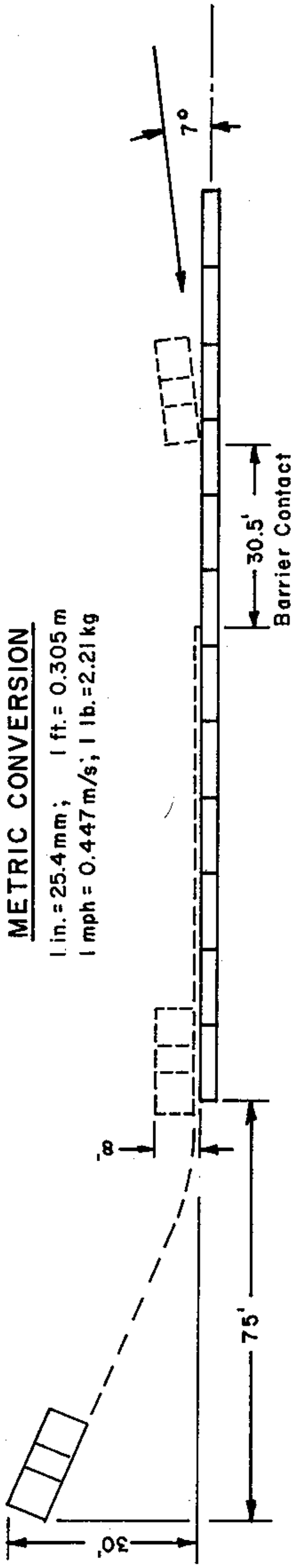
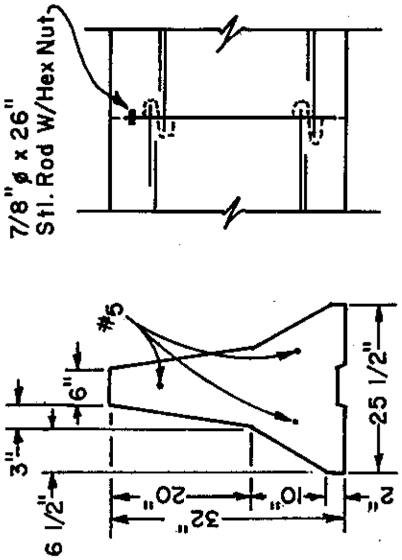


METRIC CONVERSION

1 in. = 25.4 mm; 1 ft. = 0.305 m
1 mph = 0.447 m/s; 1 lb. = 2.21 kg



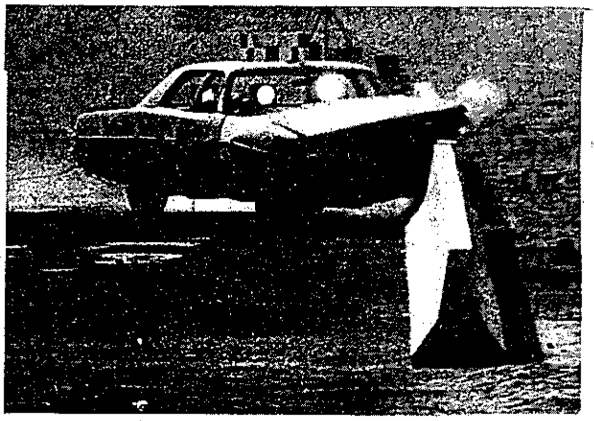
Test No. 291
Date 3/8/72
Vehicle . . . . 1969 Dodge Polara
Vehicle weight . . . . . 4860 lbs
(w/dummy & instrumentation)

Impact speed 65mph
Impact angle . . . . 7°
Vehicle damage: TAD. . . . LD-2
VDI. . . 12LDMS1

Barrier. . . . unanchored precastCMB.
Joint connection . . . . . Pinned
Closed gap
Segment/barrier lengths ft. 12.5/150
Max. Perm. Lateral Joint Displ. 6-1/4in

Vehicle deceleration(max 50msec.Avg)
Lateral. . . . . 3.4g's
Longitudinal . . . . . . 1.2g's
Dummy Restraint. . . . . lap belt
Max. Vehicle rise/roll . . . 2.3ft/18°

Figure 4, DATA SUMMARY SHEET



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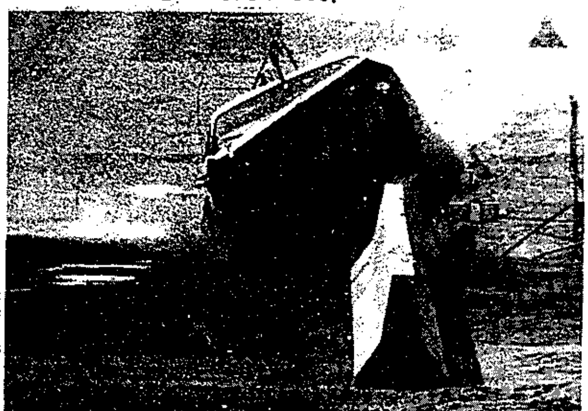
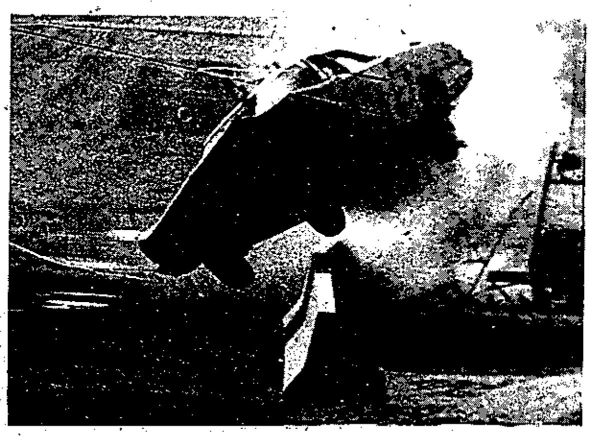
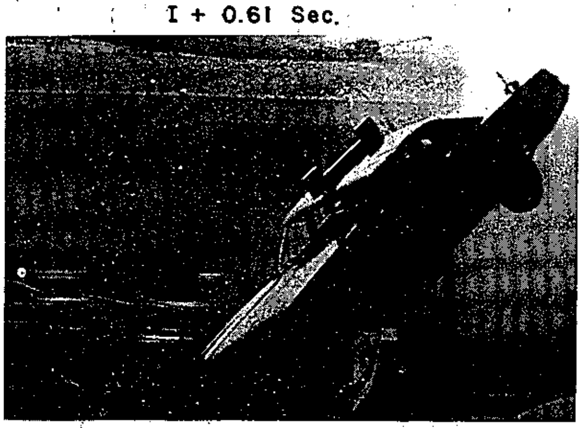


I + 0.22 Sec.



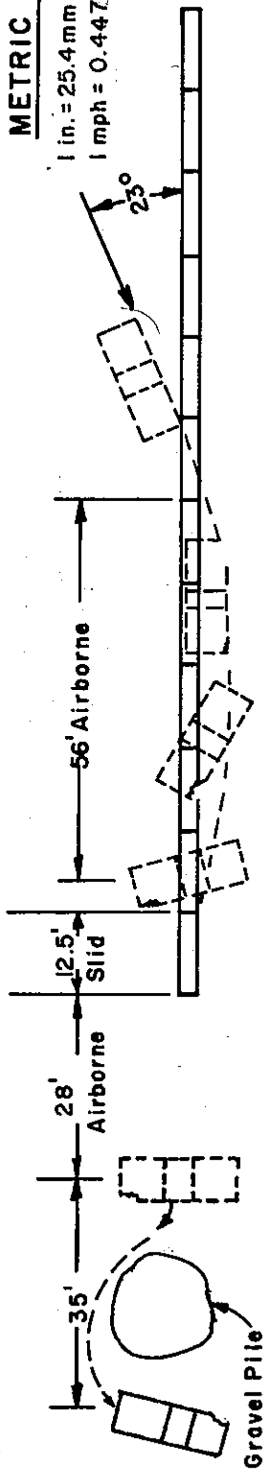
I + 0.61 Sec.



I + 0.95 Sec

METRIC CONVERSION

1 in. = 25.4 mm; 1 ft. = 0.305 m
1 mph = 0.447 m/s; 1 lb. = 2.21 kg



Test No. 292
Date 3/8/72
Vehicle. . . . . 1969 Dodge Polara
Vehicle weight . . . . . 4860 lbs
(w/dummy & instrumentation)

Impact speed 68mph
Impact angle . . . . 23°
Vehicle damage: TAD. FLQ-6;LBQ-3
VDI. . . 10LFEW5;
09LBEW2

Barrier. . . . unanchored precastCMB.
Joint connection . . . . . Pinned;
Closed gap
Segment/barrier lengths ft. 12.5/150
Max. Perm.Lateral Joint Displ.22-1/4in

Vehicle deceleration (max. 50msec. Avg.)
Lateral. . . . . 11.8g's
Longitudinal . . . . . . .6.8g's
Dummy Restraint. . . . . .lap belt
Max.Vehicle rise/roll. . . 7.0ft/61°

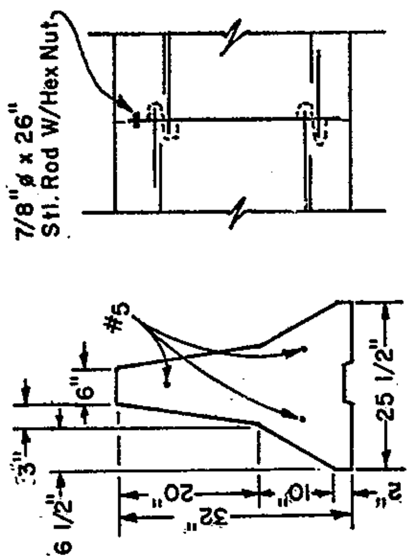
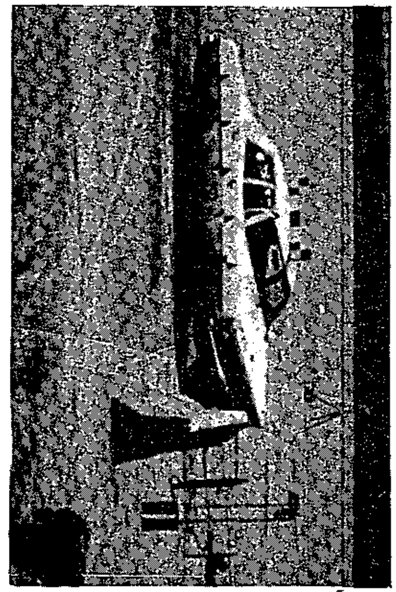
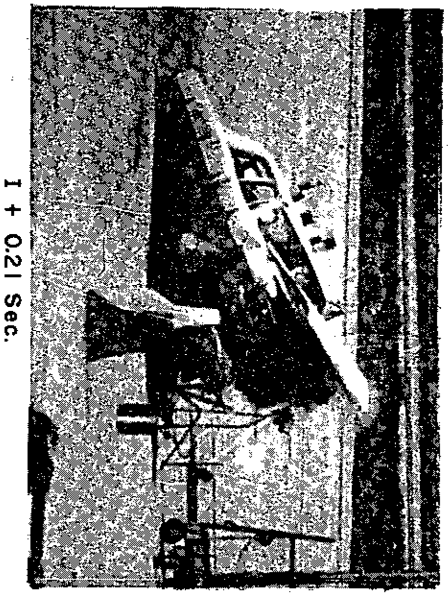


Figure 5, DATA SUMMARY SHEET

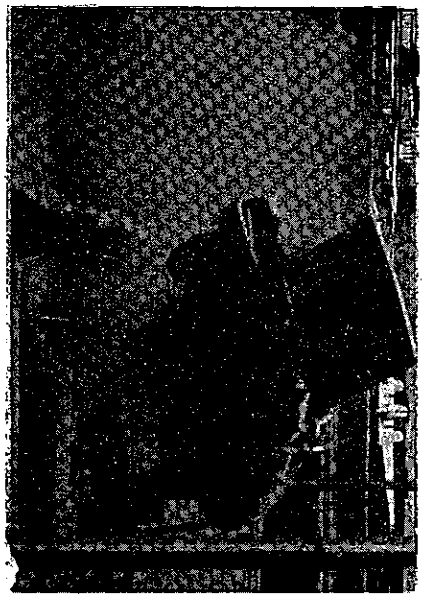


I + 0.02 Sec.

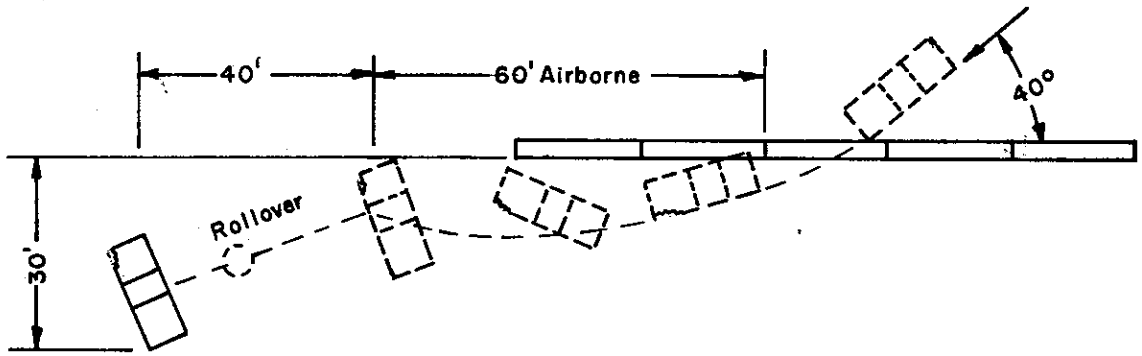


I + 0.21 Sec.

I + 0.45 Sec.

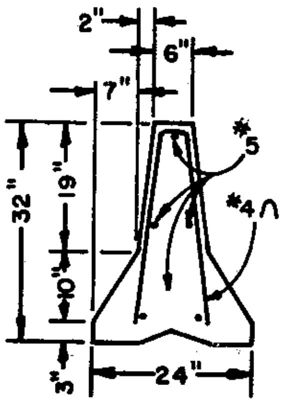


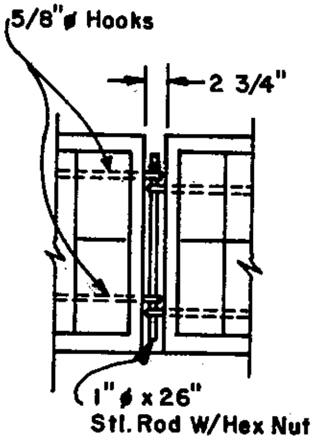
I + 0.84 Sec.



METRIC CONVERSION

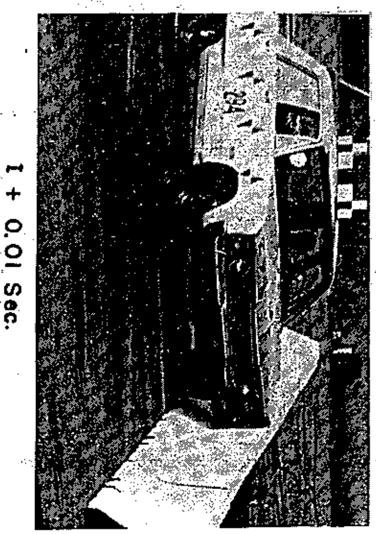
1 in. = 25.4 mm; 1 ft. = 0.305 m
1 mph = 0.447 m/s; 1 lb. = 2.21 kg





Barrier. . . . unanchored precastCMB.	Test No. 29
Joint connection . . . . . . Pinned; Open gap	Date 5/10/7
Segment/barrier lengths ft. . 20/100	Vehicle. . . . 1969 Dodge Polar
Max. Perm.Lateral Joint Displ.11-1/8in	Vehicle weight . . . . .4860 lb (w/dummy & instrumentation)
Vehicle deceleration (max. 50msec.Avg.)	Impact speed 66mph
Lateral. . . . . .6.5g's	Impact angle . . . . 40°
Longitudinal . . . . 12.8g's	Vehicle damage: TAD. FL-6;L&RT-
Dummy Restraint. . . . . . .lap belt	VDI. . . 11FYEW
Max.Vehicle rise/roll. . . 7.1ft/18°	00TPG0

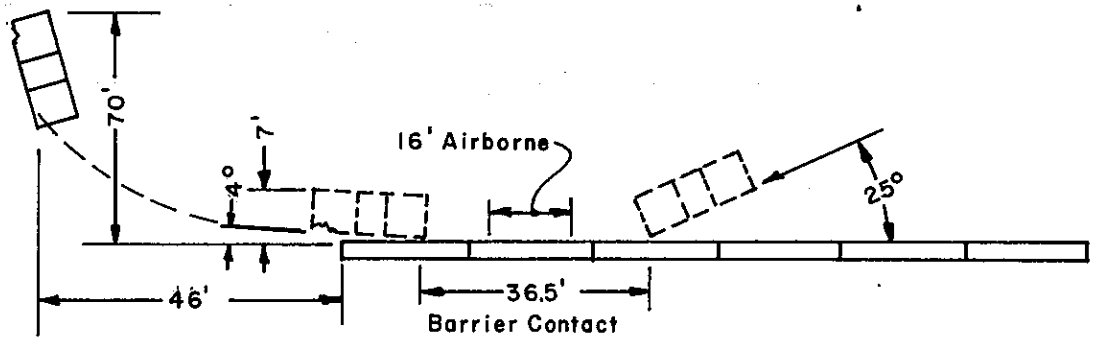
DATA SUMMARY SHEET


I + 0.01 Sec.


I + 0.23 Sec.

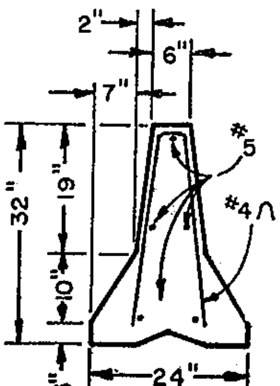

I + 0.50 Sec.

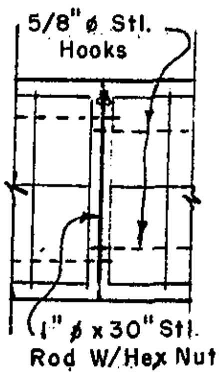

I + 1.13 Sec.



METRIC CONVERSION

1 in.=25.4 mm; 1 ft.= 0.305 m
1 mph= 0.447 m/s; 1 lb.=2.21 kg



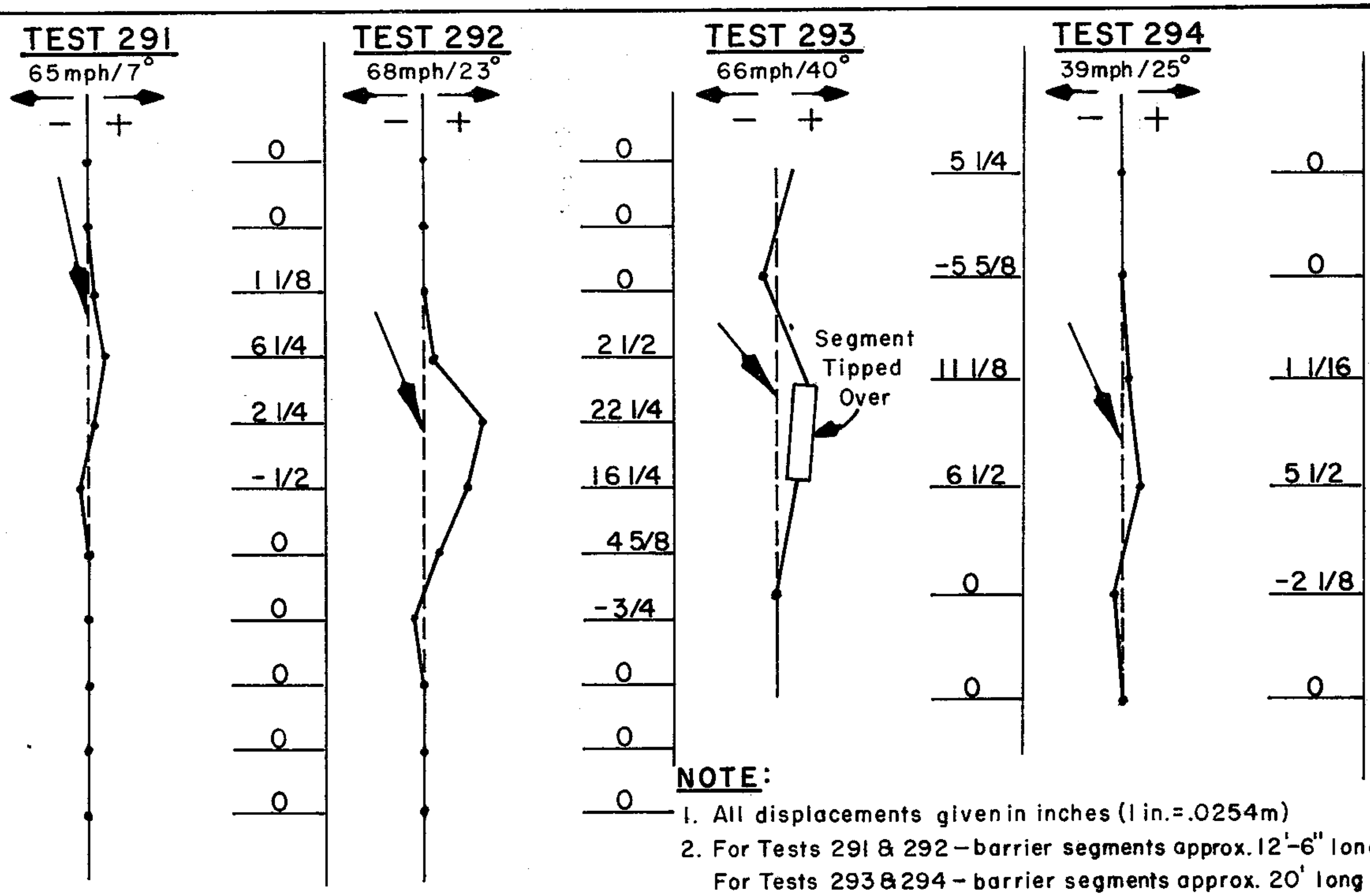


Barrier. . . . unanchored precastCMB.
Joint connection . . . . . . Pinned; Closed gap
Segment/barrier lengths ft. . 20/120
Max. Perm.Lateral Joint Displ.5-1/2in.

Vehicle deceleration (max 50msec.Avg.)
Lateral. . . . . .5.5g's
Longitudinal . . . . .2.7g's
Dummy Restraint. . . . . . .lap belt
Max.Vehicle rise/roll. . . 2.7ft/33°

Test No. 29
Date 11/20/7
Vehicle. . . . 1968 Dodge Polara
Vehicle weight . . . . .4700 lbs
(w/dummy & instrumentation)

Impact speed 39mph
Impact angle . . . . 25°
Vehicle damage: TAD. . . . FL-
VDI. . . 11FLEW3

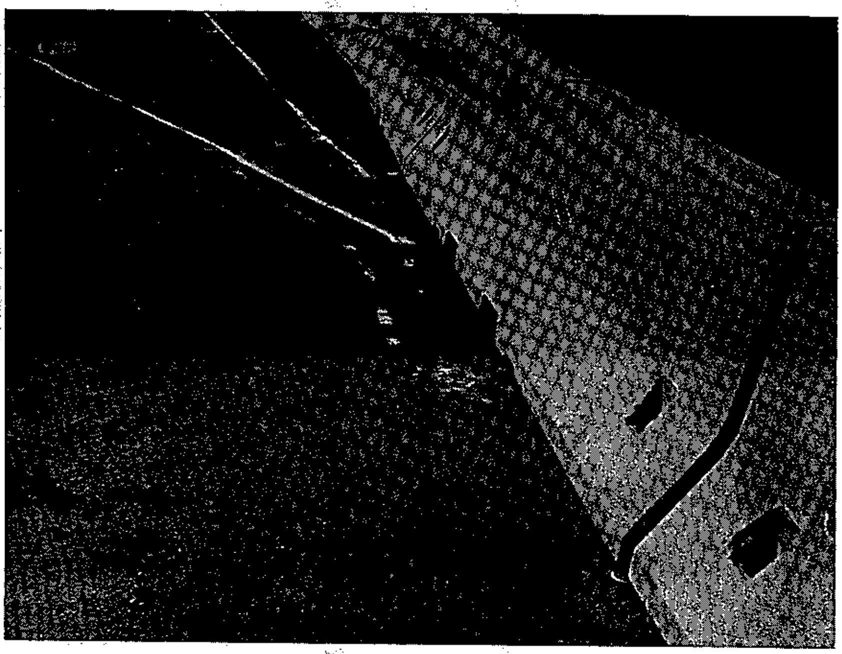


NOTE:

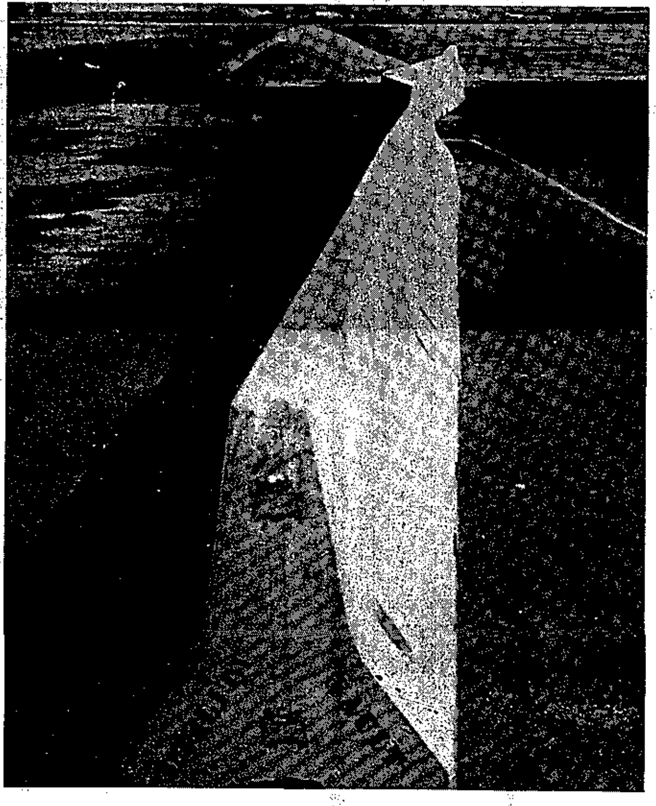
1. All displacements given in inches (1 in.=.0254m)
2. For Tests 291 & 292 – barrier segments approx. 12'-6" long;
   For Tests 293 & 294 – barrier segments approx. 20' long
3. Joint movements plotted on exaggerated scale.

PERMANENT LATERAL DISPLACEMENT OF BARRIER JOINTS

Figure 7

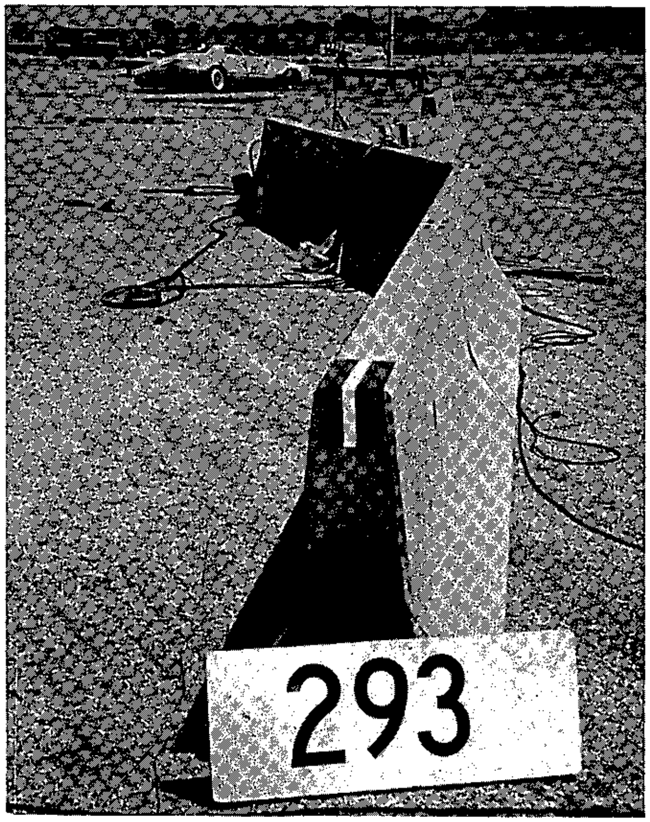


Test 291

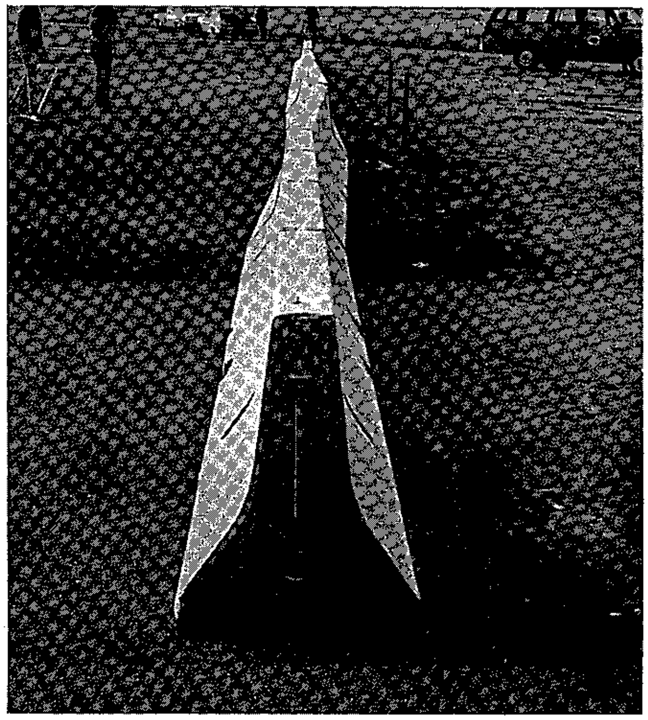


Test 292

Figure 8, Barrier Movement

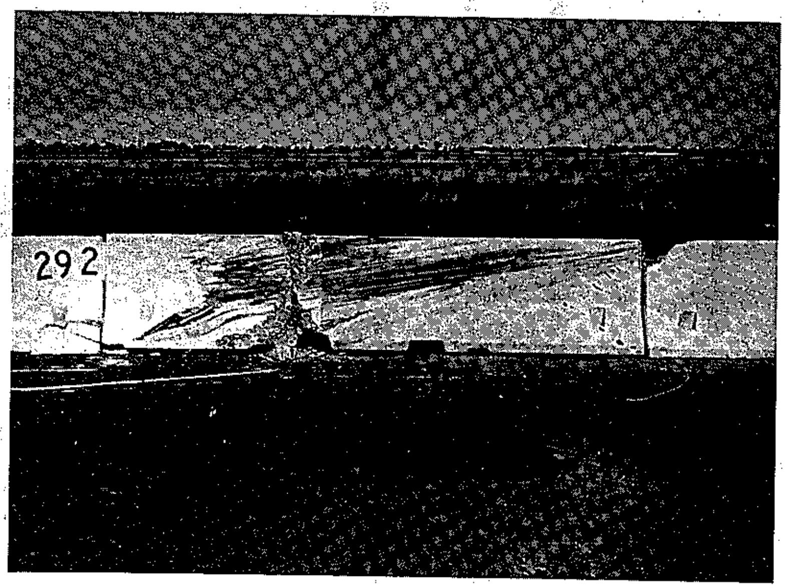


Test 293



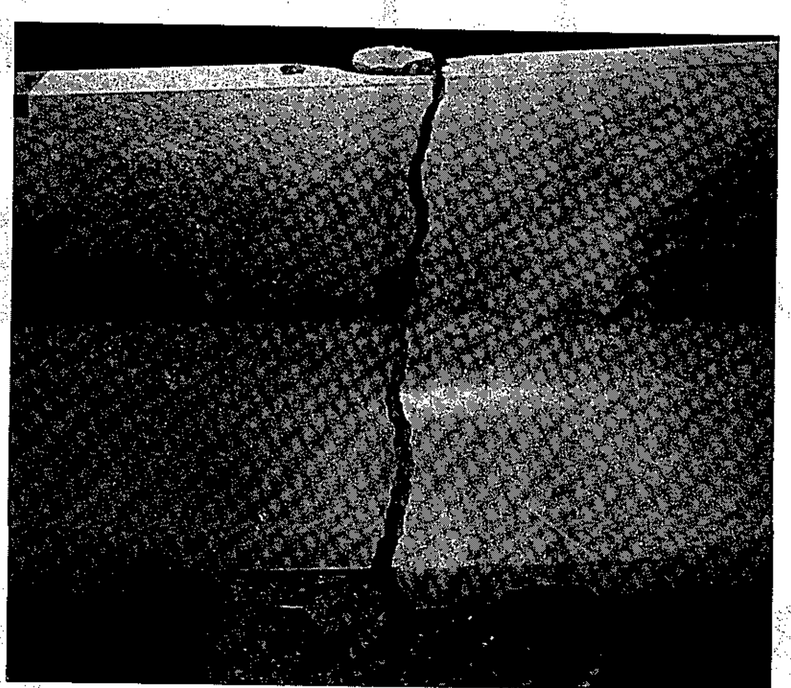
Test 294

Figure 9, Barrier Movement



Impact Side of
Barrier;

Compression Failure
at Point of Impact



Back Side of
Barrier

Figure 10, Barrier Damage, Test 292

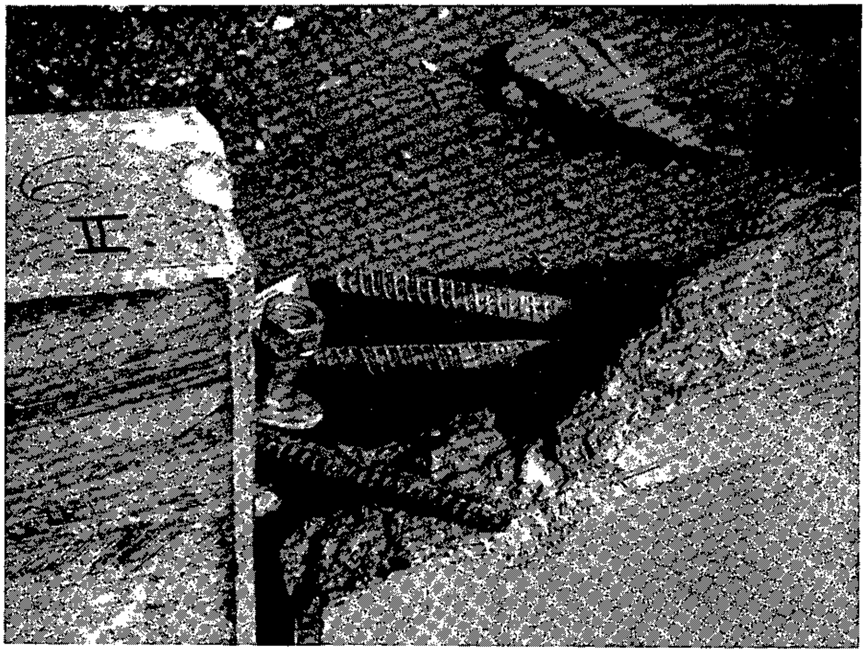


Figure 11, Top Hinge Rebar Pull-Out Failure (view
of impact side of barrier), First Joint
Downstream from Impact, Test 292

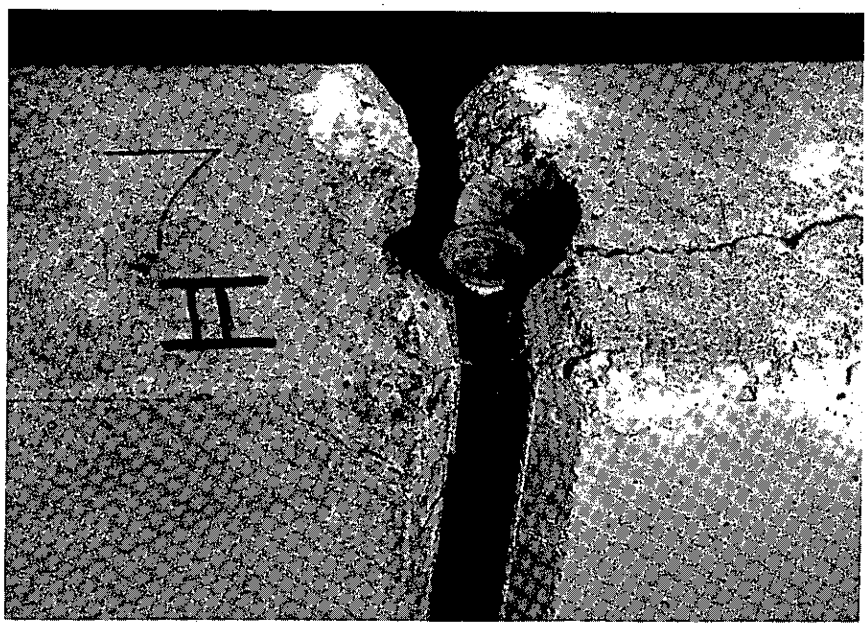
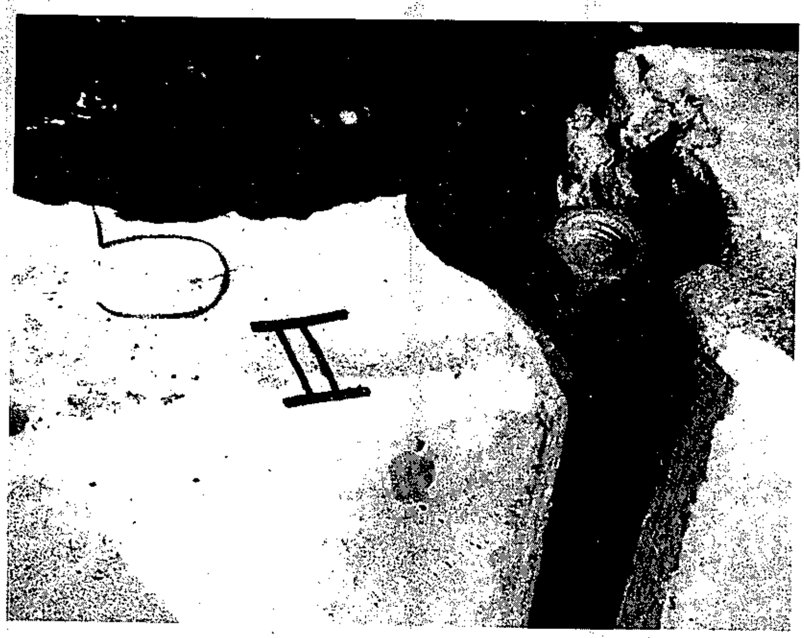


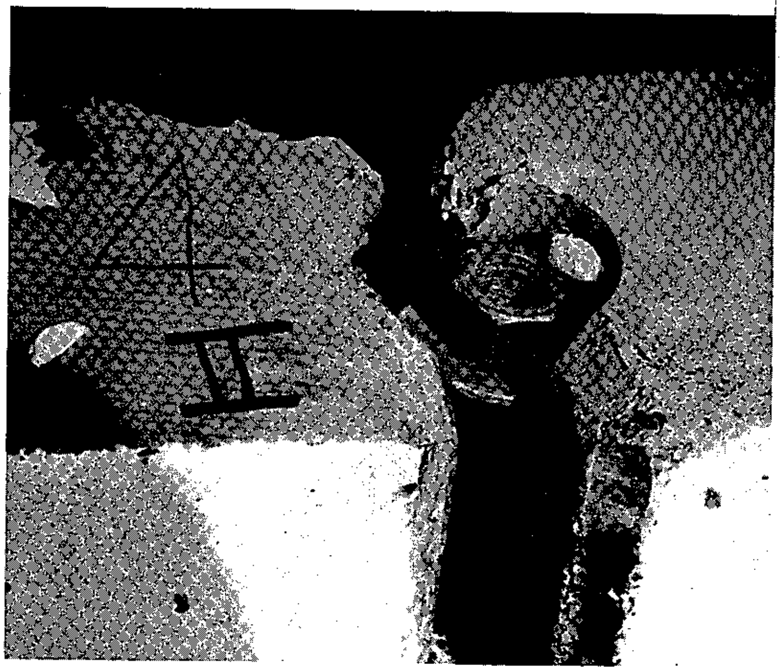
Figure 12, Probable Bond Failure of Top Hinge Rebar
(view of impact side of barrier), Second
Joint Downstream from Impact, Test 292

Impact Side
of Barrier



Back Side
of Barrier

Figure 13, Concrete Spalling at Joint 5
(first joint upstream from impact),
Test 292

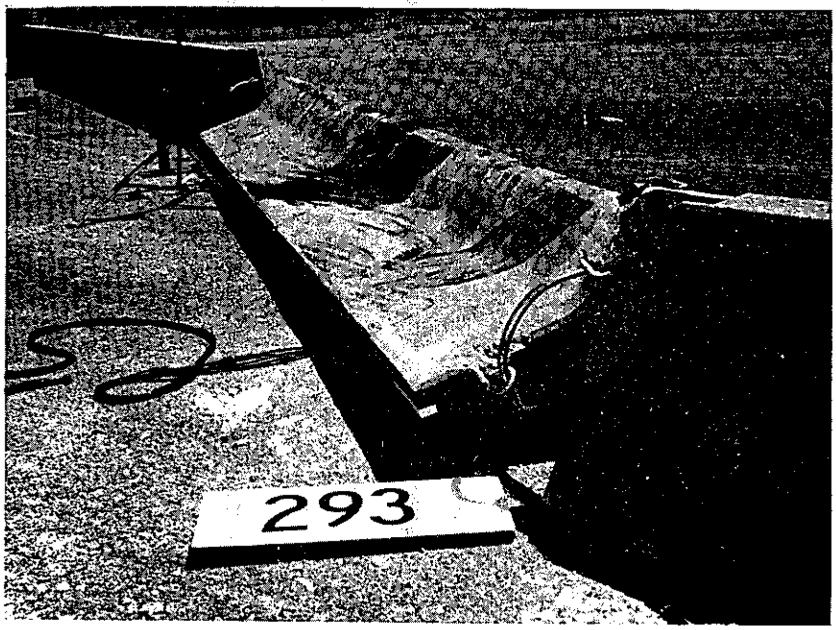


View of Back Side of Barrier

Figure 14, Concrete Spalling at Joint 4 (second joint upstream from impact), Test 292

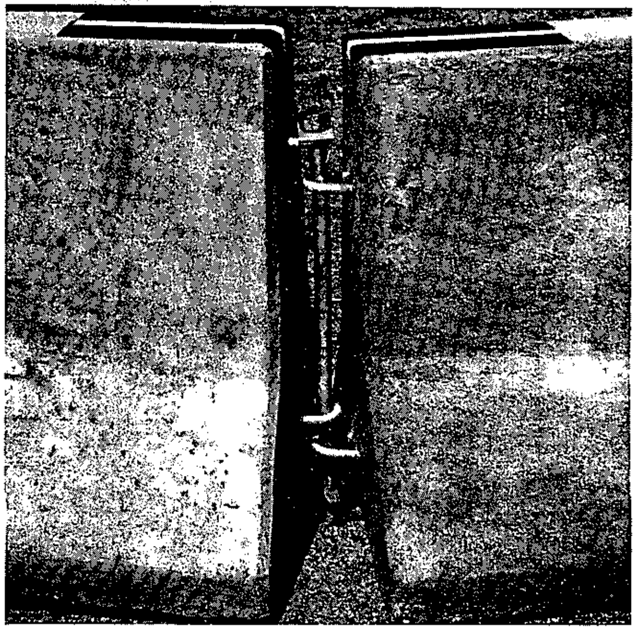
View of Back Side of Barrier

Figure 15, Concrete Spalling at Joint 6 (first joint downstream from impact) Test 292



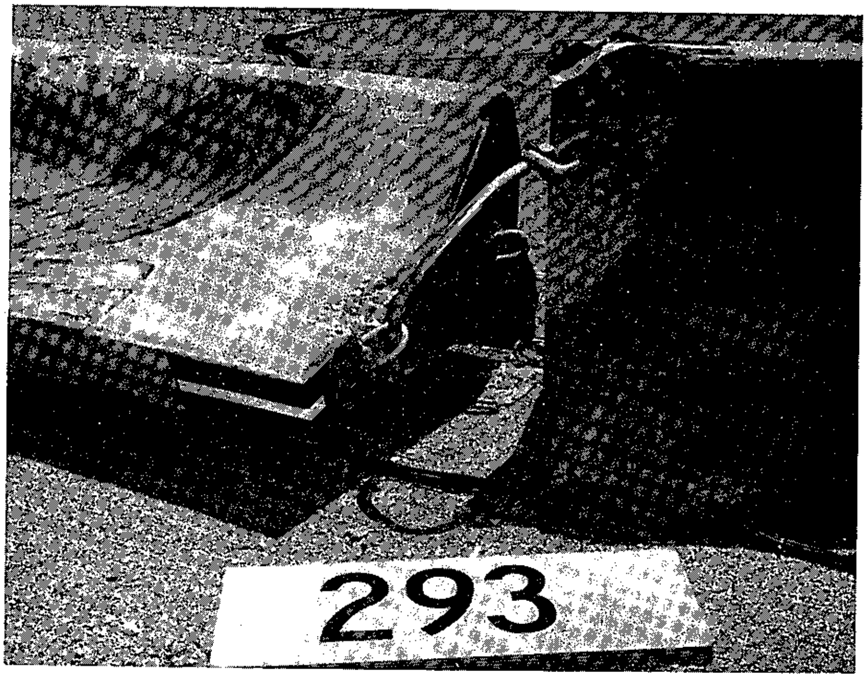
View of Back Side of Barrier

Figure 16, Bent Hinge Bars and Steel Rods at Joints 2 and 3 (first joints upstream and downstream of impact, respectively), Test 293



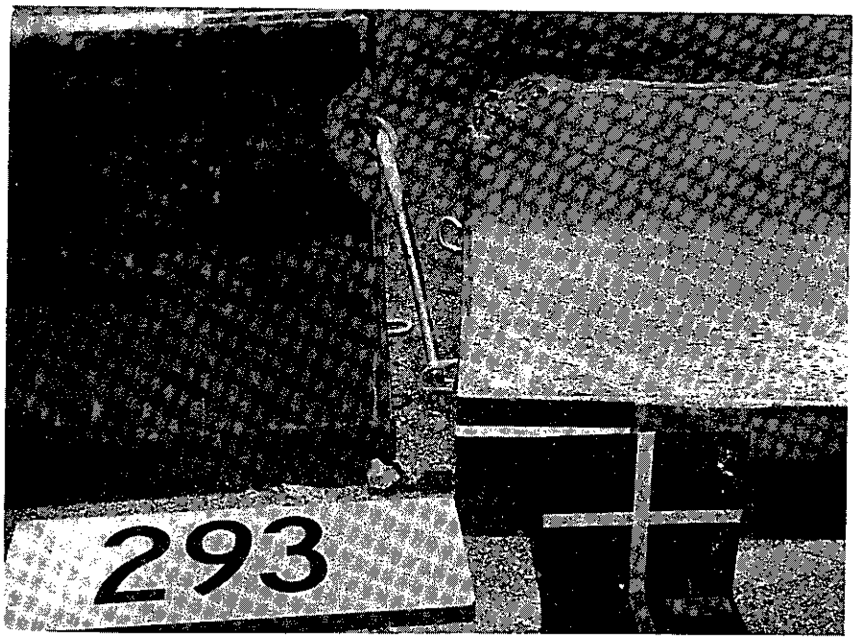
View of Impact Side of Barrier

Figure 17, Bent Steel Rod at Joint 1 (second joint upstream from impact), Test 293



Joint 2

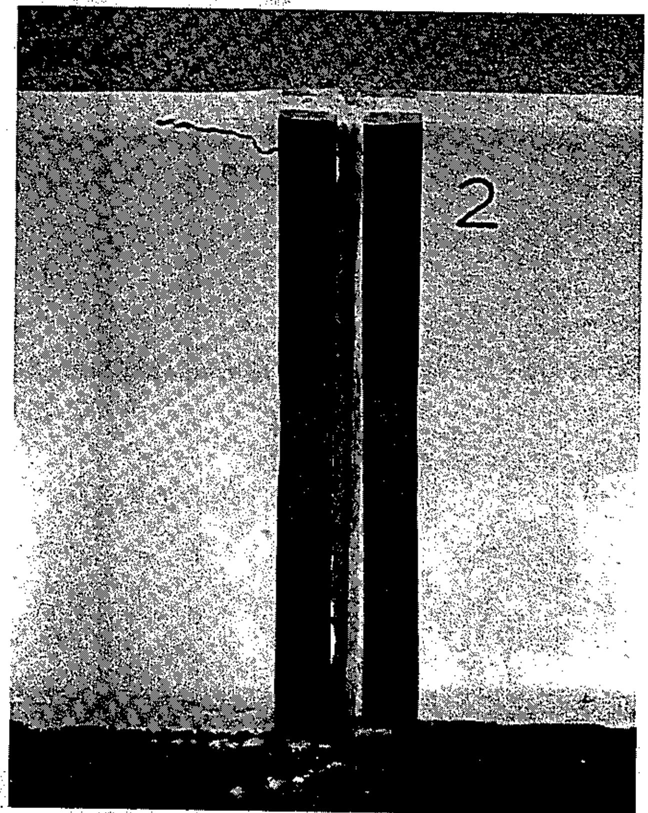
View of Back
Side of Barrier



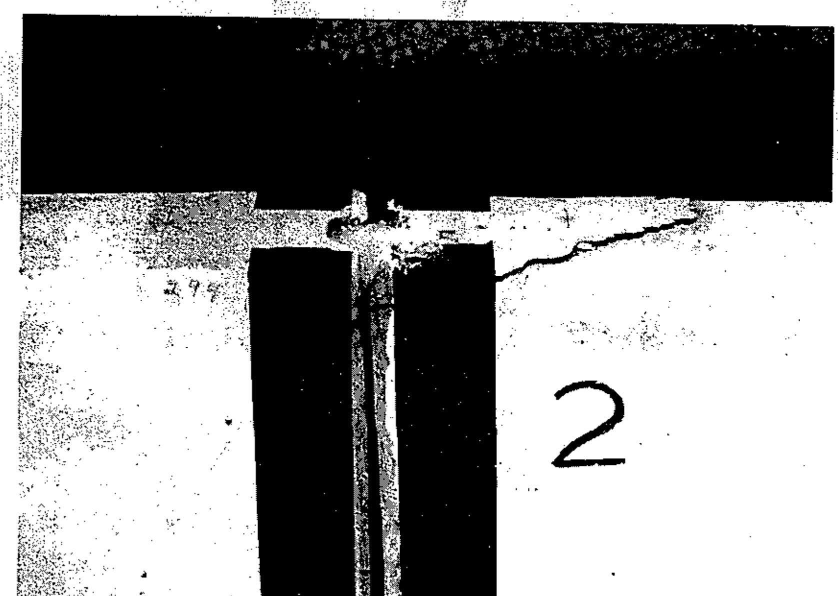
Joint 3

View of Back
Side of Barrier

Figure 18, Concrete Spalling at Joints 2 and 3 (first joint upstream and downstream of impact, respectively), Test 293

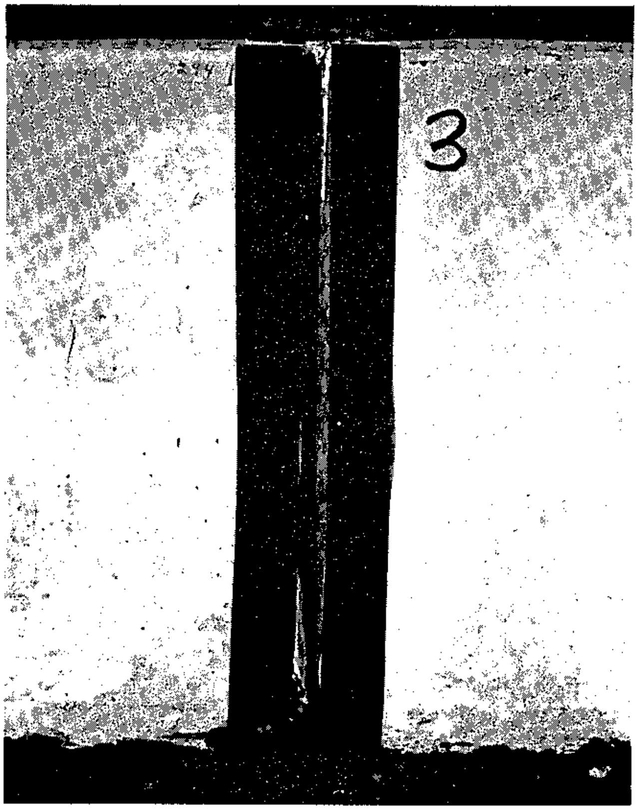


View of Impact
Side of Barrier

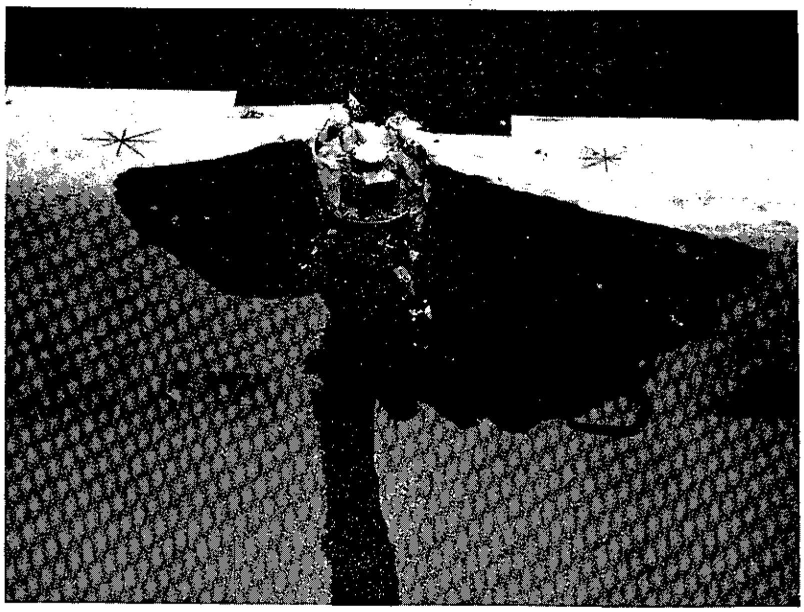


View of Back
Side of Barrier

Figure 19, Concrete Spalling at Joint 2 (second joint upstream from impact), Test 294

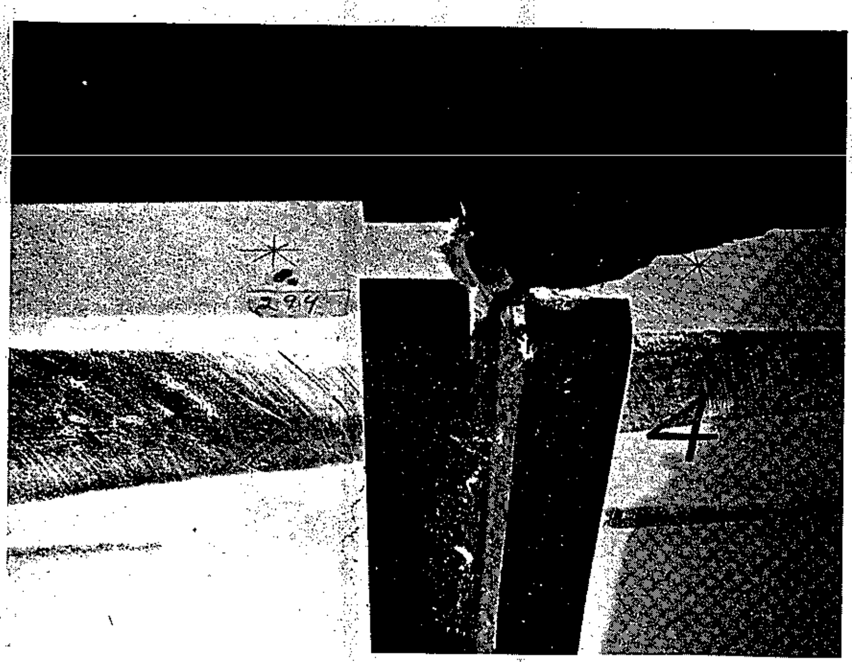


View of Impact
Side of Barrier

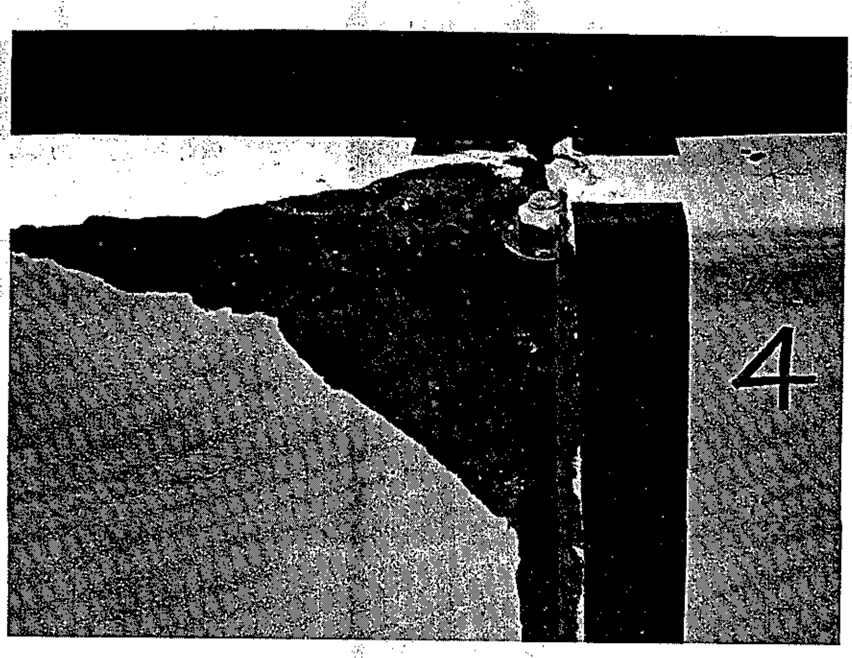


View of Back
Side of Barrier

Figure 20, Concrete Spalling at Joint 3 (first joint upstream from impact), Test 294

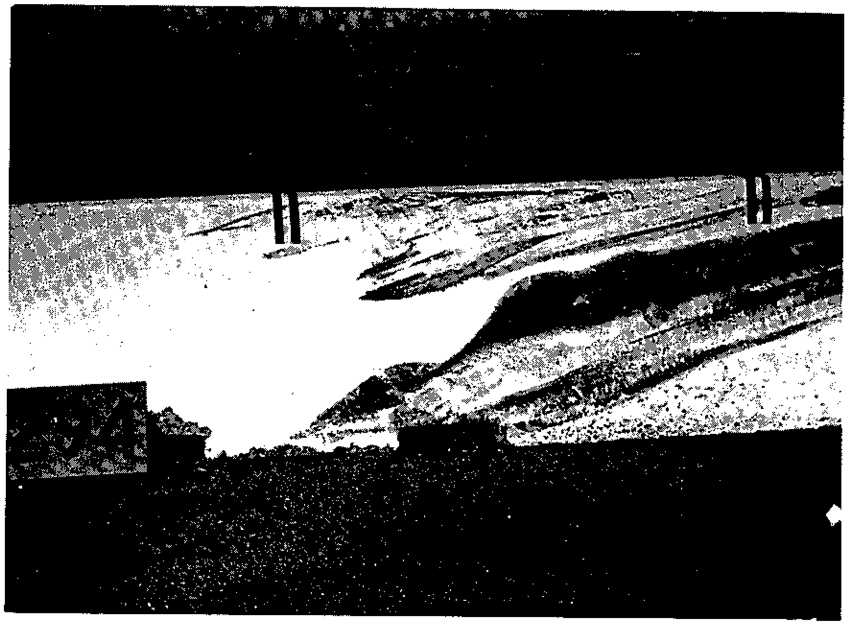


View of Impact Side of Barrier

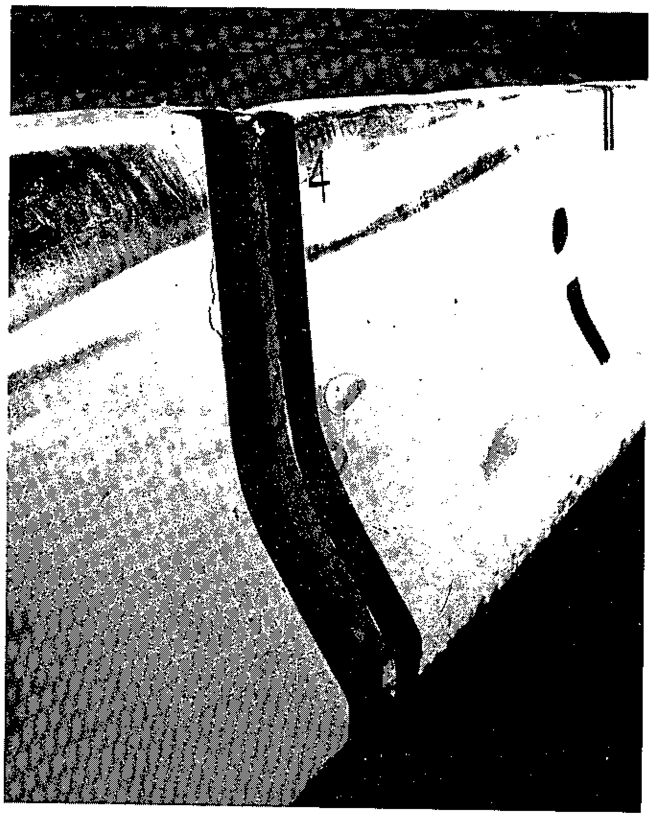


View of Back Side of Barrier

Figure 21, Concrete Spalling at Joint 4 (first joint downstream from impact), Test 294



View of Impact
Side of Barrier



<u>Joint 4</u>

(first joint
downstream from
impact)

Figure 22, Barrier Scuff Marks and Scrapes, Test 294

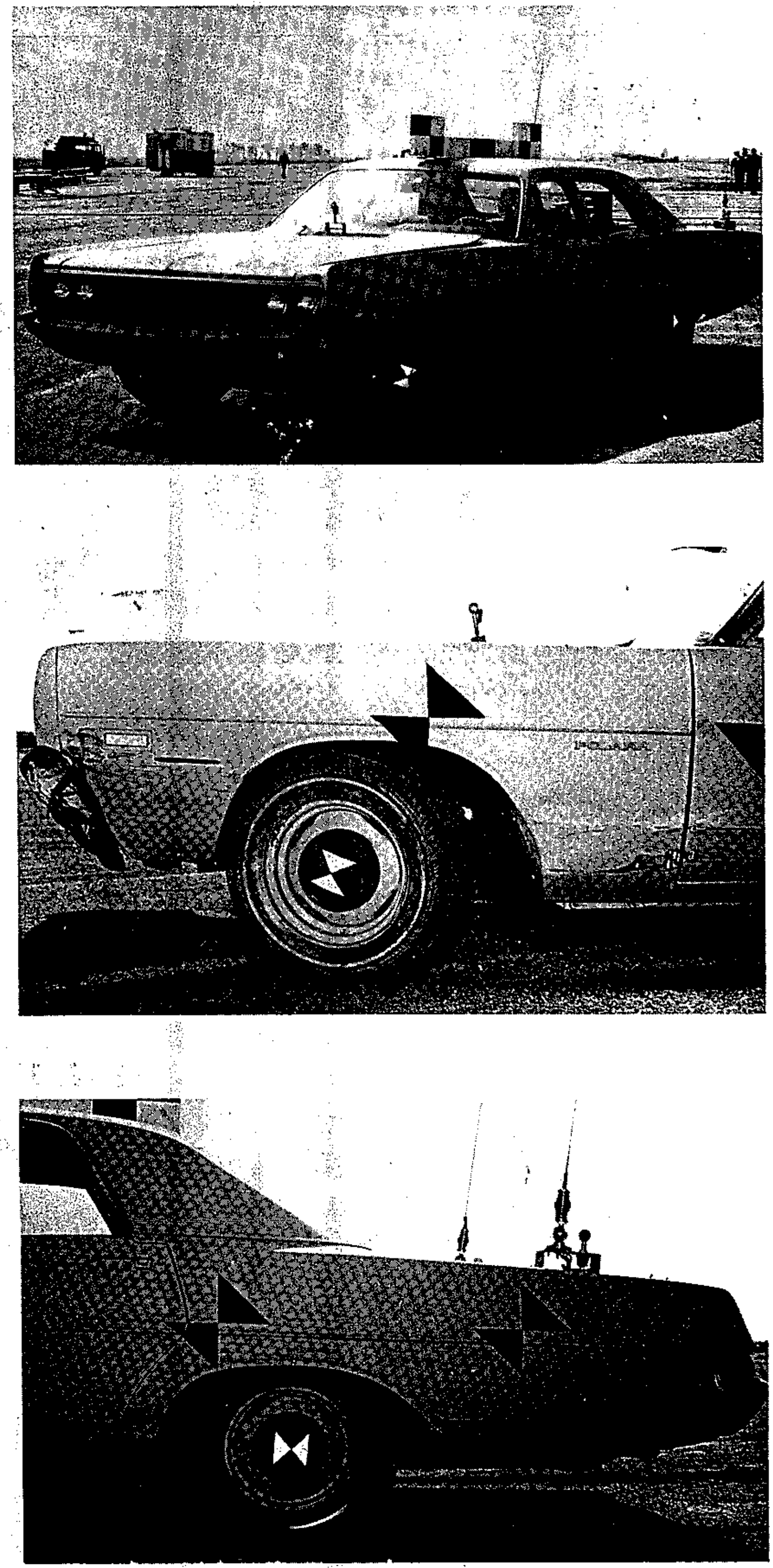
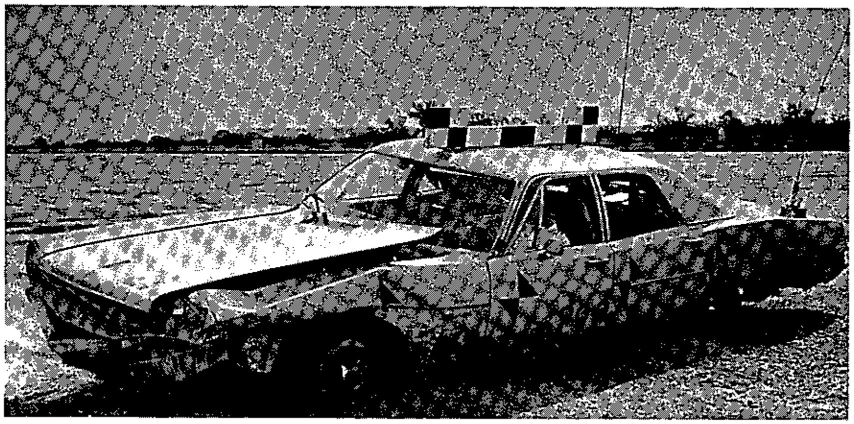
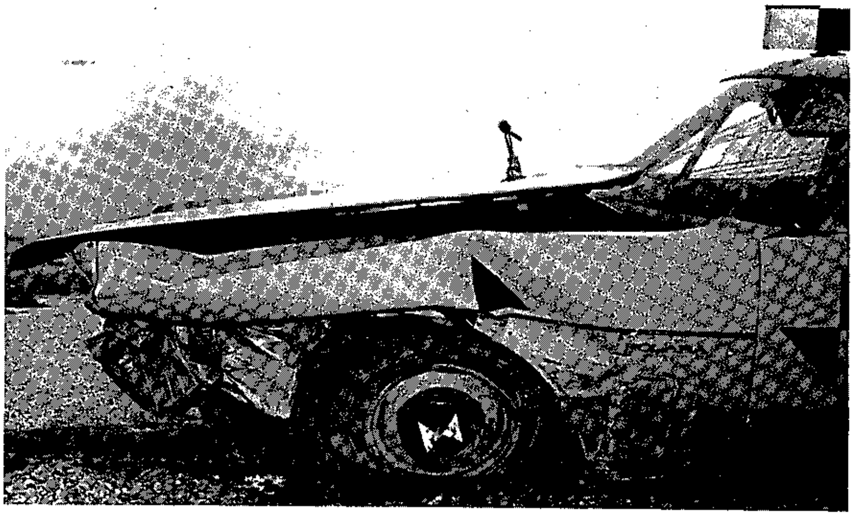


Figure 23, Vehicle Damage, Test 291





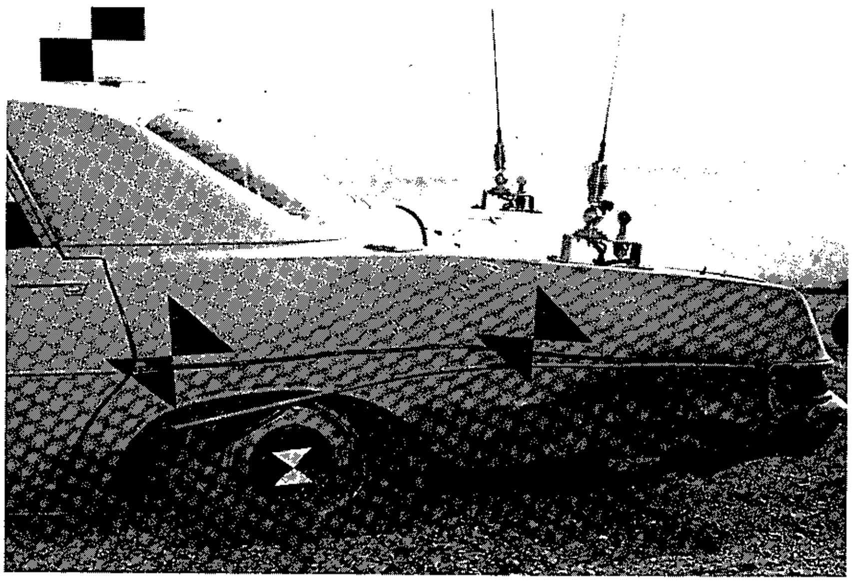
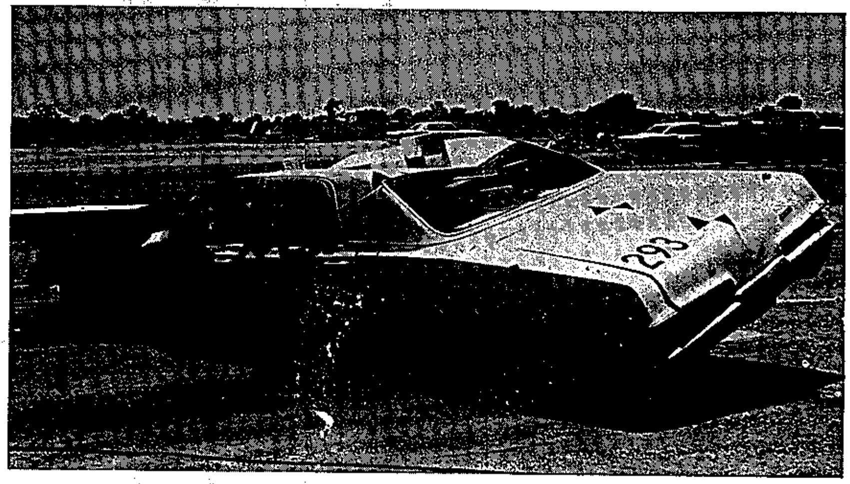


Figure 24, Vehicle Damage, Test 292



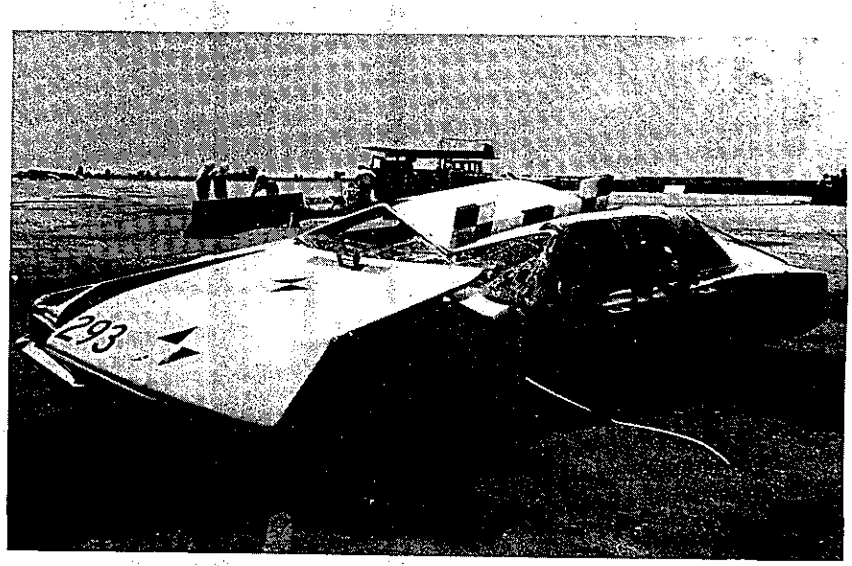
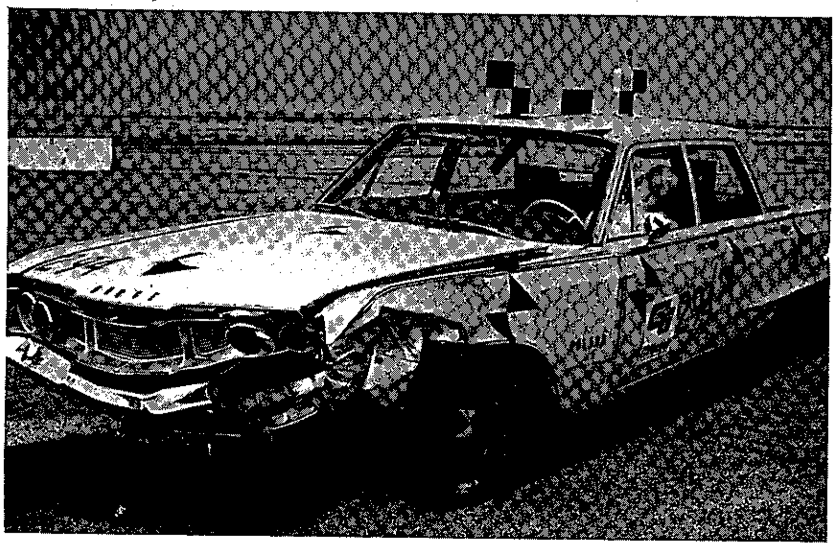


Figure 25, Vehicle Damage, Test 293



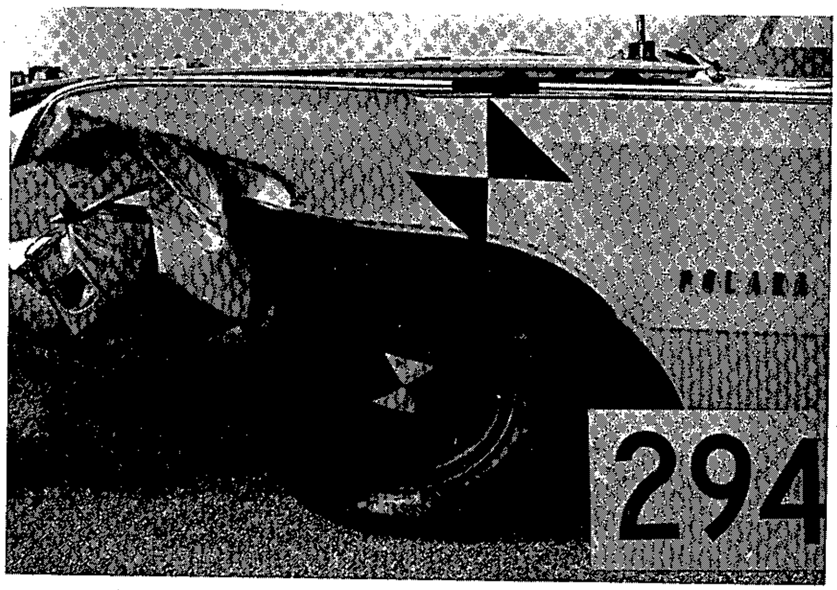


Figure 26, Vehicle Damage, Test 294

TABLE 1, DATA SUMMARY FOR PRECAST CMB CRASH TESTS (14)

			BARRIER				VEHICLE TEST PARAMETERS							VEHICLE BEHAVIOR & DAMAGE											BARRIER MOVEMENT		
REF. NO.	TEST NO.	TEST DATE	NAME	SEGMENT/ BARRIER LENGTHS	ANCHORAGE	CONNECTION BETWEEN SEGMENTS	YEAR & MAKE	WEIGHT LBS.	IMPACT VELOCITY MPH.	IMPACT ANGLE	TOTAL KINETIC ENERGY ft. kips	LATERAL COMPONENT KINETIC ENERGY ft. kips	POINT OF IMPACT ft. (15)	VEHICLE DECELERATION G'S (10) LONG.	LAT.	EXIT ANGLE (16)	EXIT SPEED MPH(17)	MAX. RISE FT.(18)	MAX. ROLL ANGLE (19)	BARRIER CONTACT DISTANCE FT.	AIRBORNE DISTANCE FT.	MAX. REBOUND DISTANCE FT.(11)	TAD(12)	VDI(13)	MAX. PERMANENT LATERAL DEFLECTION IN.	MAX. TILT ANGLE°	COMMENTARY
CALIFORNIA	291	3/72	PRECAST NJ SHAPE	12.5/150	NONE	CLOSED PINNED JOINTS 7/8" Ø STEEL ROD THROUGH OVERLAPPING #6 REBAR HOOKS CAST IN ENDS	1969 DODGE POLARA	4860	65	7	686	10	9	1.2	3.2[4]	Ø	54	2.3	16	30.5	Ø	26	LD-2	12LDMS1	6 1/4	0	VEHICLE REDIRECTED; MINOR CONCRETE SPALLING AT ONE JOINT.
	292								68	23	752	115	11.5	6.8	11.6[4]	Ø	55	7.0	61	18	56	12	FLQ-6 LBQ-3	10LFEW5 05LBEW2	22 1/4	16°	VEHICLE NOT REDIRECTED; VEHICLE LAUNCHED AIRBORNE LANDING NEARLY CROSSWISE TO ℄ OF BARRIER; SEGMENT FRACTURED AT IMPACT; MAJOR SPALLING AT THREE PINNED JOINTS; SEGMENTS LACKED SUFFICIENT REINFORCEMENT.
	293	5/73		20/100		OPEN PINNED JOINT; 1" Ø STL. ROD THROUGH OVERLAPPING 5/8" Ø HOOKS			66	40	708	292	18.7	12.8[4]	6.5[4]	−10	48	7.1	16	11	60	−26	FL-6 LBRT-5	11FYEW6 00TPG04	11 1/8	SEGMENT TIPPED OVER	VEHICLE NOT REDIRECTED; VEHICLE LAUNCHED AIRBORNE BEHIND BARRIER & ROLLED OVER; BARRIER SEGMENT TIPPED OVER; CONNECTING HOOKS & RODS BENT.
	294	11/74		20/120		CLOSED PINNED JOINT; STEEL ROD THROUGH OVERLAPPING 5/8" Ø HOOKS	1968 DODGE POLARA	4700	39	25	239	43	9.2	2.7[4]	5.5[4]	4	30	2.7	33	36.5	16	70	FL-4	11FLEW3	5 1/2	9°	VEHICLE REDIRECTED (LOW IMPACT VELOCITY); MINOR CONCRETE SPALLING AT THREE PINNED JOINTS.
SWRI[1]	WCB-1	7/74	WELSBACH PRESTRESSED	30/180	GROUT BED; 1" Ø x 4' STL. DOWELS DRVN. AT 1ST, 2ND 5TH & 6TH SEG	STL. ℄	1963 MERCURY	4500	61.7	24	573	95	13.4	9.9[5]	13.5[5]	NA				17.8	NA				Ø	NA	VEHICLE REDIRECTED; BARRIER SEPARATED FROM GROUT BED IN THE IMPACT AREA; NO OTHER BARRIER DAMAGE.
	WCB-1A	5/75	PRECAST NJ SHAPE			MALE/FEMALE INTERLOCK	1968 PONTIAC	4500	62.7	24	592	98	13.2	9.4[5]	9.9[5]					17.6					2 1/2	NA	VEHICLE REDIRECTED; BARRIER SEPARATED FROM GROUT BED IN THE IMPACT AREA; CONCRETE CRACKING BACK SIDE OF FIRST SEGMENT DOWNSTREAM OF IMPACT.
	CMB-18	NA	PRECAST CONFIGURATION F SHAPE	20/100	SEGMENT ENDS SET ON 3/4" THICK STYROFOAM PADS	30"x3"x1 1/2" VERTICAL CONC. SHEAR KEY; 12"x3"x1/4" STEEL ℄ BOLTED AT BASE ON EACH SIDE OF JOINT.	NA	4500	62	25	578	103	5	NA													VEHICLE REDIRECTED; SEGMENT FRACTURED AT IMPACT AND 5.5 FT. PAST 1ST. JOINT DOWNSTREAM FROM IMPACT; MINIMAL SEGMENT REINFORCEMENT. 11 FT. SEGMENT DISLODGED FROM REST OF BARRIER AND TIPPED OVER.
	CMB-20				1" GROUT BED		1974 AMC AMBASSADOR		63	24.8	597	105	5.6	6.1[5]	9.8[5]	NA	NA	NA	56	14.7	NA	NA	NA		0	NA	VEHICLE REDIRECTED; TENSION CRACKS AT LIFTING VOIDS LOCATED APPROX. 5 FT. BOTH SIDES OF JOINT 2. (1ST. JOINT DOWNSTREAM FROM IMPACT).
	CMB-24				SAME AS CMB-18		1974 AMC AMBASSADOR		56.4	24.1	476	80	4.7	3.5[5]	4.9[5]	NA	NA	NA	26	44.5	NA	NA			41	NA	VEHICLE REDIRECT; SEGMENTS REMAINED ATTACHED; CONC. FAILURES AT JOINTS 1, 2 & 3; DIAGONAL CRACKING OF FEMALE JOINT.
TTI[2]	CMB-1	1975	PRECAST NJ SHAPE W/8" TOP & 27 1/2" BASE	30/90	1" A.C. BACK SIDE OF BARRIER	THREE #8x18" REBAR DOWELS CAST IN ONE SEGMENT & GROUTED TO NEXT SEGMENT	1966 PONTIAC	4500	60.5	23.5	550	88	7	1.6[6]	7.5[6]	7	48.0[9]	NA	18	NA	NA	NA	FL-5.5	11FLEW3	0	NA	VEHICLE REDIRECTED; NO BARRIER DAMAGE.
	CMB-2			30/90	NONE	THREE #8x18" REBAR DOWELS SET IN FORMED GROOVES & GROUTED	1965 OLDS.	4540	59.8	24.2	543	91	7	1.1[7]	6.3[7]	3	49.3[9]	NA	18	NA	NA	NA	FL-4.5	11LFEW2	13 1/2	NA	VEHICLE REDIRECTED; SEVERE CRACKING AT BOTH JOINTS.
FRANCE[3]	MI-SCB 01/253	8/72	PRECAST (FRENCH) NJ SHAPE W/20" BASE	20/200	CONC. FTG. 16"x20"x12" DEEP, 3.3 FT. FROM EACH SEGMT. END CONNECTED TO SEGMENT W/1 DOWEL	LAPPED ENDS CONNECTED W/2-7/8"x6" HORIZ. PINS IN UPPER STEM OF CMB SECTIONS	404 PEUGEOT	2640	53	20	248	29	0	IMPACTOGRAPH USED		7	NO DATA			9	NO DATA		NA		Ø	NO DATA	VEHICLE REDIRECTED; VERTICAL CRACK IN ONE SEGMENT; THE ENDS OF THREE SEGMENTS DAMAGED.
	MI-SCB 02-254	6/72					404 PEUGEOT	2660	59	10	310	9	~10			SMALL				15					Ø		VEHICLE REDIRECTED
	MI-SCB 03/260	10/72					404 PEUGEOT	2420	50	26	202	39	~5	14/10[8]	12/7[8]	14				9					1		VEHICLE REDIRECTED; TWO SEGMENT ENDS DAMAGED; THREE FOOTINGS TILTED IN SOIL.

(1) Southwest Research Institute, references 5, 6, & 7, in report
(2) Texas Transportation Institute, reference 8 in report
(3) Organisme National De Securite Routiere, Laboratoire des Chocs, reference 9 in report.
(4) Avg. of two max. 50 msec averages.
(5) Reduced from high speed film.
(6) Avg. for 206 msec. interval
(7) Avg. for 223 msec. interval.
(8) Peak/mean
(9) Velocity parallel to barrier
(10) Highest 50 msec. averages from accelerometer data unless noted.
(11) Max. distance (incl. width of vehicle) from face of barrier
(12) Vehicle Damage Scale (National Safety Council)
(13) Collision Deformation Classification (SAE J224a)
(14) 1in=25.4mm; 1 ft.=0.305m; 1mph=0.447m/sec; 1 ft-k=1.36kJ
(15) Distance to nearest downstream joint
(16) Direction of travel of vehicle c.g. immediately following final contact with barrier.
(17) Speed of vehicle c.g. immediately following final contact with barrier.
(18) Max. trajectory height of either/or left side wheel of vehicle above ground.
(19) Max. rotation of vehicle about the longitudinal axis of vehicle away from face of barrier.
(20) ~ = approx.

Discussion of Test Results

The safety performance appraisal factors discussed in the three following sections are structural adequacy, impact severity, and vehicle trajectory hazard as defined in NCHRP Report 153, "Recommended Procedures for Vehicle Crash Testing of Highway Appurtenances"(4).

Table 1 summarizes the test parameters and results of the three unanchored precast CMB designs tested by Caltrans along with tests of other precast barrier designs conducted by Southwest Research Institute(5,6,7), Texas Transportation Institute(8), and the Organisme National De Securite, Laboratoire des Chocs of France(9).

1. Structural Adequacy.

The NCHRP Report 153 guidelines state that the test barrier shall redirect the vehicle; the vehicle shall not penetrate or vault the barrier or be pocketed or snagged by the barrier; the vehicle shall not decelerate abruptly, or spinout, or rollover during or after impact; and that no barrier components or debris shall penetrate the vehicle or present an undue hazard to other traffic(4).

Test 291. During this 7°/65 mph impact test, the vehicle was smoothly redirected by the test barrier without rolling excessively and exited parallel to the barrier. Permanent deflection of the barrier segments, 6 1/4 inches maximum, did not adversely affect the dynamic performance of the barrier.

Other than some minor spalling at the joints closest to the impact area, the barrier suffered no structural damage.

Barrier debris would not have encroached into adjacent traffic lanes. No vehicle or barrier components penetrated the passenger compartment of the vehicle during the impact.

Test 292. At a larger impact angle of 23°, with the same barrier used for Test 291, the test vehicle impacting at 68 mph was not smoothly redirected by the test barrier. Tilting of the barrier and lateral barrier movement launched the vehicle into a high airborne trajectory path. Yawing of the vehicle was about 90° by the time it slid off the top edge of the last barrier segment and hit the ground.

The barrier suffered severe structural damage at the point of impact in addition to major spalling at three pinned joints. Connecting rods and hinge bars were bent.

The large pieces of barrier debris which were scattered about 25 feet from the barrier would have posed a hazard to traffic on the opposite side of a median.

Test 293. Instead of the closed joint design previously tested, the second barrier design featured open pinned joints, 2 3/4 inches wide, between each segment. Also, the length of each barrier segment was increased to 20 feet to add more mass to the barrier for resisting lateral barrier movement and more reinforcing steel was used.

Again, the test vehicle was not smoothly redirected by the barrier, but was launched on a high airborne trajectory and yawed clockwise almost 90° by the time it landed.

The first barrier segment impacted was pushed over backwards during the test because torsional moments were not transmitted across the open joints to adjacent barrier segments. The steel hinge bars twisted and the connecting rods were pulled out of the lower embedded hinge bars in a manner similar to nails being pulled from a board by a hammer. The unusually large angle of impact (40°) combined with the 66 mph impact velocity undoubtedly added to the severity of the barrier damage and the high airborne trajectory of the vehicle. Some minor concrete spalling was the only additional barrier damage.

There was no hazardous flying debris. However, the engine of the test vehicle intruded about 3 inches into the passenger compartment during the impact.

Test 294. Barrier segments were 20 feet long and were reinforced similarly to those in Test 293, but had closed pinned joints similar to those used in Tests 291 and 292.

The vehicle was redirected from this 25 degree angle impact. However, the vehicle climbed to the top of the barrier and the left wheels rode along the top edge of the segments for 24.5 feet.

The impact velocity of 39 mph was much less than the planned impact velocity of 60 mph. Only 44% of the impact kinetic energy recommended by NCHRP Report 153(4) was imparted to the barrier during this impact. Even with these moderate test conditions, the barrier segment initially impacted tipped back off line about 9° and translated laterally about 5 inches during impact. Consequently, under standard strength test conditions of 4500 lb vehicle/60 mph/25° impact angle, the barrier segments would have rotated and deflected laterally much more, thus causing vehicle instability with vaulting and yawing. However, if the impact angle had been less than 25°, with an impact speed of 39 mph, the barrier might have been completely effective in redirecting the vehicle.

Other than minor spalling of the barrier concrete at three joints, there was no structural damage to the barrier, and, consequently, no hazardous debris was generated. There was no intrusion of barrier or vehicle components into the passenger compartment during this test.

Summary. The amount of joint flexibility and the ability of the joints to transmit impact loads to adjoining segments is illustrated by the following example and Figure 27. In the barrier design for Test 294, there is a maximum amount of horizontal "play" or looseness between rods and hinge bars of 1/2 inch, i.e., if two adjoining segments are stretched out in opposite directions to the

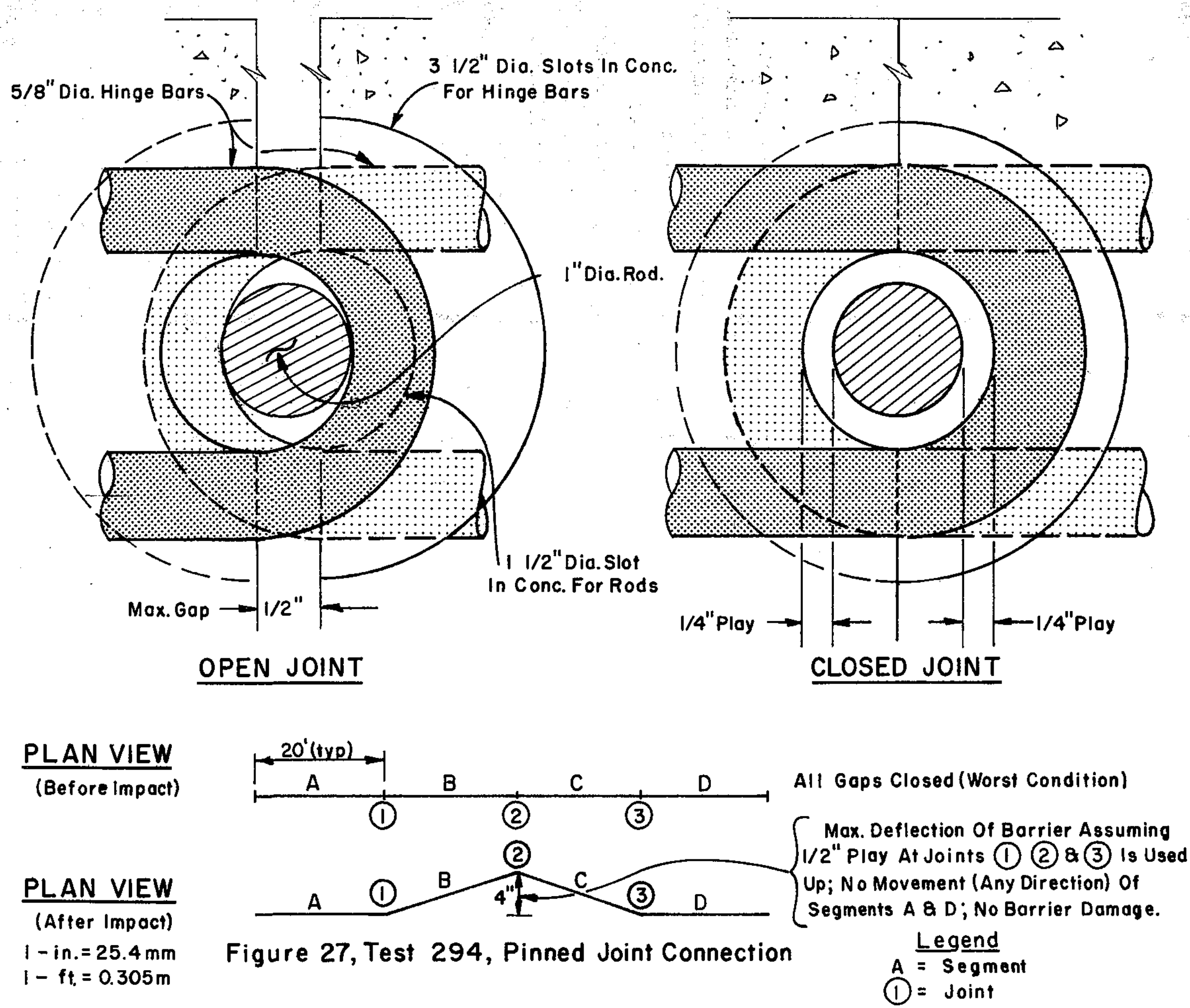


Figure 27, Test 294, Pinned Joint Connection maximum extent, the gap between segments will be 1/2 inch wide, Figure 27 open joint. If the segment ends are initially butted together, then there is a potential amount of "play" of 1/2 inch at each joint, Figure 27 closed joint. If two adjoining segments are deflected laterally until the 1/2 inch "play" is used up at the three end joints, then the maximum lateral deflection of the joint between the two segments will be about 4 inches, assuming 20 foot segment lengths with no movement of the segments adjoining the two which were deflected and no barrier damage.

In addition to potential lateral movement of barrier joints due to horizontal "play" at the joints, the two segments can also rotate about their joints due to the vertical "play" of 11/16 inches between the 5/8 inch diameter hinge bars that slide into 2 inch high by 3 1/2 inch half round slots in each segment end.

The amount of play in the joints must be minimized to facilitate load transfer across joints during impact. However, the joint "play" must be compatible with reasonable construction and field assembly tolerances. This "play" at joints is an inherent structural weakness of unanchored pinned end precast CMB designs.

Strength tests were conducted on samples of the connecting rods, hinge bars, and concrete used in the three barrier designs. The results show that those materials all met the design specifications, Figure 18A, Appendix.

In summary, none of the three barrier designs were considered structurally adequate when subjected to the severe impact test conditions used in Tests 292, 293, and 294. However, the CMB design used in Test 291 and subjected to moderate impact test conditions was structurally adequate for those impact conditions. Also, had the impact angle been slightly less in Test 294 (where structural adequacy was marginal) the barrier design probably would have proven to be effective.

When compared to the results of tests on continuous cast-in-place or slipformed CMB with footings or other anchorage, summarized in Table 1 of reference 10, the dynamic performance of the precast CMB designs used for this project was quite different. The continuous CMB did not move laterally or tilt during impact. In these tests, the vehicles were redirected and acceptable post impact trajectories were recorded in most tests in contrast to the erratic vaulting vehicle behavior which occurred during two of the Caltrans precast CMB tests. It is evident that more structural continuity is required at precast CMB joints with pinned end connections to obtain barrier performance similar to that expected from continuous CMB.

2. Impact Severity

Vehicle Decelerations. NCHRP Report 153(4) recommends two crash tests for longitudinal barrier designs. The first test ("Test 1") is basically a check on the strength and stability of the barrier. A 4500 lb vehicle is to impact the barrier at a speed/angle of 60 mph/25°. The second required test ("Test 2") is conducted to determine the performance of lighter weight vehicles, 2250 lb, at less severe, more typical impact speed/angle values of 60 mph/15°. This second test is used to judge impact severity with reference to Table 4, Section IIA of NCHRP Report 153(4).

> "Where test article functions by redirecting vehicle, maximum vehicle acceleration (50 msec avg.) measured near the center of mass should be less than the following values:
>
> Maximum Vehicle Accelerations (g's)
>
> | Lateral | Longitudinal | Total | Remarks |
> |---|---|---|---|
> | 3 | 5 | 6 | Preferred |
> | 5 | 10 | 12 | Acceptable |
>
> These rigid body accelerations apply to impact tests at 15 deg. or less."

Tests 292, 293, and 294 represent "Test 1" strength tests on three different barrier designs. Since all three tests revealed structural deficiencies, no "Test 2" impact severity tests were conducted. Nevertheless, the maximum values for acceleration shown above are included for comparison with the values in Table 1. This table contains vehicle deceleration data for Tests 291 through 294 and also tests on precast CMB by other agencies. As might be expected, the deceleration values for Tests 292 and 293 exceed the acceptable standard values. However, deceleration values for Test 294 were satisfactory, because of the low actual impact speed of 39 mph. Deceleration values for Test 291 also met the standard because the angle of impact was only 7°.

The vehicle weight of 4860 lbs and impact speeds of 65 to 68 mph in Tests 291, 292, and 293 were selected before NCHRP Report 153(4) standards of 4500 lb vehicles with 60 mph impact speeds were published. The higher test values were typical of parameters used in previous Caltrans crash tests, and were representative of highway conditions in California prior to the 55 mph speed limit. These higher vehicle weights and impact speeds clearly increased the deceleration values.

Anthropometric Dummy Response. Use of a dummy is considered optional in NCHRP Report 153(4). Electronic data from the dummy used in all four tests is included here as a further indication of impact severity. Deceleration versus time traces for accelerometers mounted in the head and chest cavities of the anthropometric dummy during the four Caltrans tests are included in the Appendix, Figures 8A through 11A. Lap belt load versus time traces for these tests are also attached in the Appendix, Figure 12A. None of the lap belt loads exceeded the 5000 lb limit specified by Federal Motor Vehicle Safety Standard 208 cited as a recommended safety evaluation guideline in NCHRP Report 153(4).

3. <u>Vehicle Trajectory Hazard</u>.

This factor "is a measure of the potential of a redirected car causing a subsequent multi-vehicle collision". Evaluation of the hazard is "based on vehicle exit speed and angle, maximum intrusion into a traffic lane or lanes during trajectory, and postcrash controllability of the vehicle"(<u>4</u>).

The final positions of the vehicles after impact are shown on the Data Summary Sheet for each test, Figures 3 through 6 at the end of the Test Results section of the report.

<u>Test 291</u>. The postcrash trajectory of the test vehicle probably would not have interfered with the flow of adjacent traffic. The test vehicle exited parallel to the barrier at a velocity of 54 mph. The rebound distance of the vehicle was 8 feet when the vehicle reached the end of the test barrier.

<u>Test 292</u>. Excessive lateral barrier movement and rotation causing vehicle vaulting during impact significantly affected the postcrash trajectory of the test vehicle. The vehicle landed downstream from the end and nearly perpendicular to the centerline of the barrier segments, but would have been involved in a secondary impact with the top of a continuous barrier installation. The possibility of a secondary barrier impact would have been extremely hazardous to adjacent traffic.

<u>Test 293</u>. Severe vehicle vaulting similar to Test 292 greatly influenced the postcrash trajectory of the test vehicle. The vehicle landed behind the test barrier and rolled over once before coming to rest. This type of vehicle trajectory could possibly have caused a secondary cross-median accident if the barrier was used in the median of a highway.

<u>Test 294</u>. The test vehicle probably would not have encroached into adjacent traffic lanes depending on the ability of the driver to control the post trajectory of the vehicle following

the impact. All tires of the vehicle remained inflated during the impact. The test vehicle exited the end of the test barrier at about 4° and 30 mph. Immediately after reaching the end of the last precast barrier test segment, the vehicle yawed clockwise in front of the barrier before the remote brakes were applied.

In summary, all three barrier designs when tested under severe impact conditions were unable to sustain a non-hazardous vehicle trajectory; however, in Test 294 where impact conditions were less severe than in Tests 292 and 293, there was a possibility that a driver could have prevented the hazardous vehicle trajectory which occurred.

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APPENDIX

Test Vehicle Equipment and Guidance Methods

Tests 291 and 292. Vehicle modifications and the guidance system used for these tests are itemized as follows:

1. The test vehicle gas tank was disconnected from the fuel supply line, drained and refilled with water. A one gallon safety gas tank was installed in the trunk compartment and connected to the fuel supply line.

2. Three wet-cell storage batteries (6, 8, and 12 volt) were mounted on the floor of the rear seat compartment. They supplied power for the remote control equipment.

3. A solenoid-valve actuated CO_2 system was connected to the brake line for remote braking. With 700 psi in the accumulator tank, the brakes could be locked in less than 100 milliseconds after activation. Brakes are activated by radio control.

4. The ignition system was connected to the brake relay in a failsafe interlock system. When the brake system was activated, the vehicle ignition was switched off. Also, any loss of steering control caused by a failure of either the radio transmitting or receiving systems would automatically energize the brake relay, thus cutting the vehicle ignition and braking the vehicle to a stop.

5. A micro switch was mounted below the front bumper and connected to the ignition system. A trip line installed near impact triggered the switch; thus opening the ignition circuit and cutting the vehicle motor prior to impact.

6. The accelerator pedal was linked to a small electric motor which, when activated, opened the throttle. The motor was activated by a manually thrown switch mounted on the top of the rear fender of the test vehicle.

7. Steering was mechanically accomplished with a 400 inch-ounce stepping motor through a V-belt driven pully attached to the steering shaft. The stepping motor was mounted on a bracket secured to the floorboard of the front seat compartment and activated through the remote radio tuned relay system for right or left turns.

8. A radio control receiver, tone actuated relays, steering pulse and handi-talkie radio were mounted on a chassis bolted to the floorboard of the trunk compartment. Whip antennas for the radio receivers were mounted on the vehicle's rear fenders.

Tests 293 and 294. The test vehicles were modified as described above in items 1 through 6. Instead of the radio controlled steering system, a cable guidance system was used to direct the vehicles into the barriers. The guidance cable,

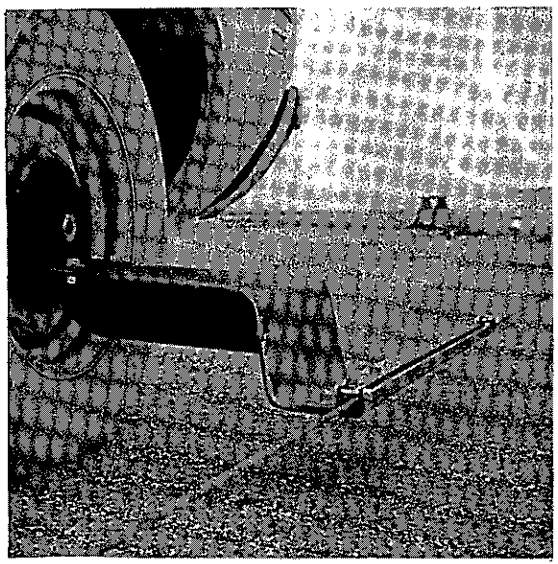


Figure 1A, Cable Guidance Bracket

anchored at each end of the vehicle path, passed through a slip-base guide bracket, Figure 1A, bolted to the spindle of one of the vehicle's front wheels. A steel angle post driven into the ground near the barrier projected high enough to knock off the guide bracket thereby releasing the vehicle from the guidance cable prior to impact.

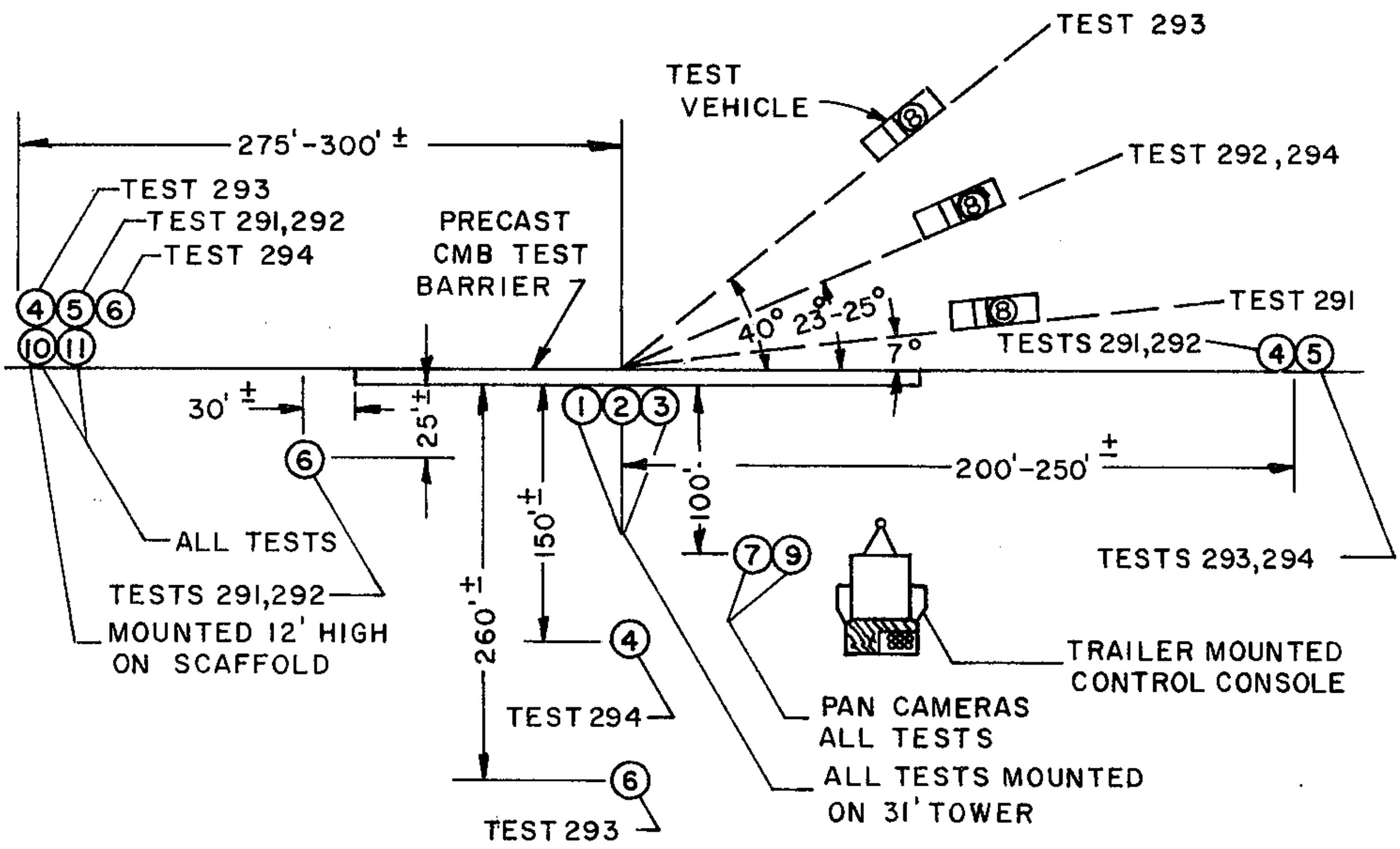
The remote brakes were controlled at the console trailer, Figure 2A, by using an instrumentation cable connected between the vehicle and the electronic instrumentation trailer, and a cable from that trailer to the console trailer. Any loss of continuity in these cables caused an automatic activation of the brakes.

Photo-Instrumentation

Data film was obtained by using seven high speed Photo-Sonics Model 16mm-1B cameras (200-400 frames per second). These cameras were located around the barriers as shown in Figure 2A, Camera Layout. All cameras were electrically actuated from a central control console, Figure 2A. An eighth Photo-Sonics Model 16mm-1B camera was placed in the test vehicle to record the motions of the anthropometric dummy during impact. This camera was triggered by a tether-line actuated switch mounted on the rear bumper of the test vehicle.

All cameras (except for the camera mounted inside the vehicle for Tests 291, 292, and 293) were equipped with timing light generators which exposed reddish timing pips on the film at a rate of 1000 per second. The pips were used to determine camera frame rates and to establish time-sequence relationships. Additional coverage of the impacts was obtained by a 70mm Hulcher sequence camera and a 35mm Hulcher sequence camera (both operating at 20 frames per second). Documentary coverage of the tests consisted of normal speed movies and still photographs taken before, during, and after each impact. Data from the high-speed movies was reduced on a Vanguard Motion Analyzer, Figure 3A.

Figure 2A
CAMERA LAYOUT[3]



CAMERA DATA[1]

(1)(2)(3) Photo-Sonics Model 16mm-1B, 13mm Lens, (275-350) FPS[2],

(4)(5)(6) Photo-Sonics Model 16mm-1B, 4" (102 mm) Lens, (300-350) FPS

(7) Photo-Sonics Model 16mm-1B, 2" (51 mm) Lens, (300-330) FPS, PAN

(8) Photo-Sonics Model 16mm-1B, 5.3mm Lens, 200 FPS, Inside Test Vehicle

(9) Bolex, 1" (25mm) Lens, 24 FPS, PAN

(10) 70mm Hulcher, 12" (305mm) Lens, 20 FPS, Sequence Camera

(11) 35mm Hulcher, 50mm Lens, 20 FPS, Sequence Cam ra

1. All cameras mounted on tripods unless otherwise noted.
2. Frames per second
3. 1 ft. = 0.305m , 1 in. = 25.4 mm

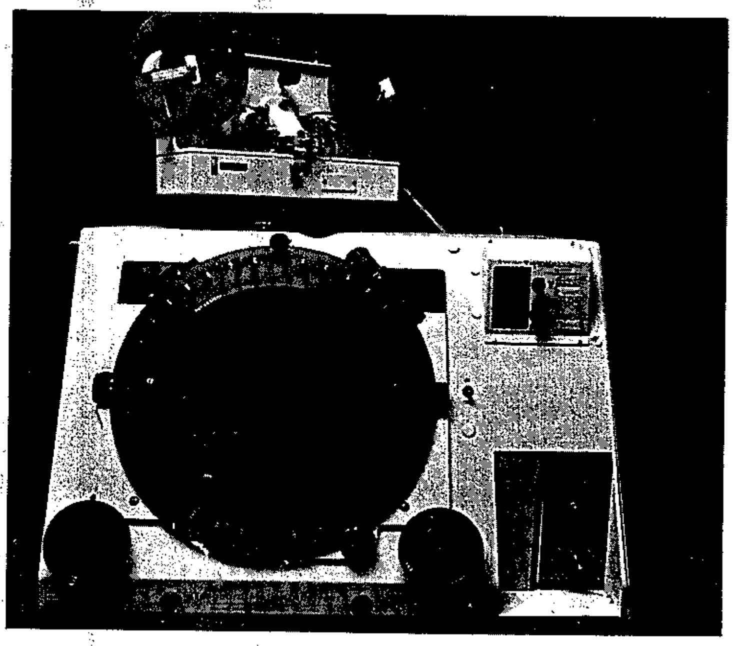


Figure 3A, Vanguard Motion Analyzer

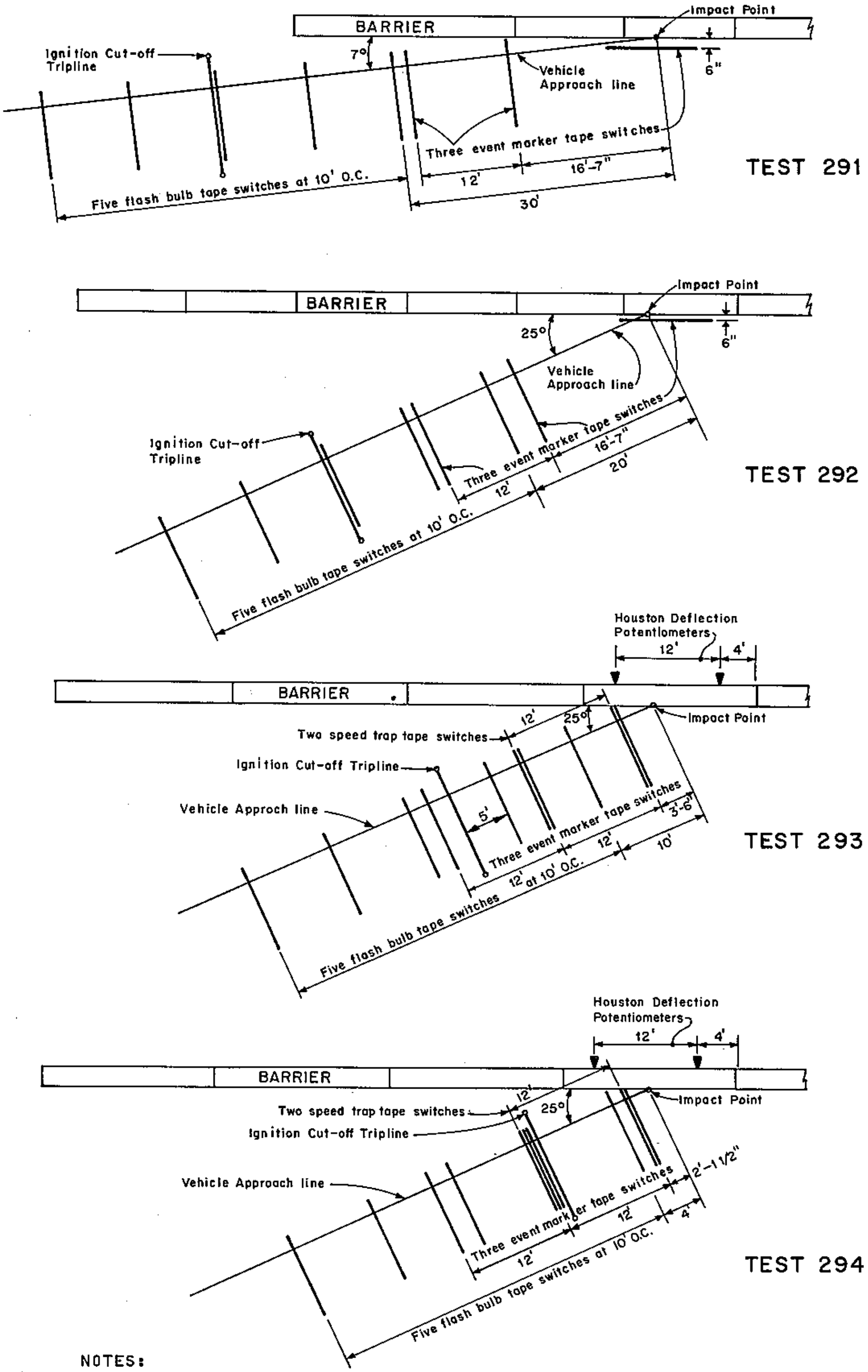
Some procedures used to facilitate data reduction for the tests are listed as follows:

1. Targets were attached to the vehicle body and to the barriers, and placed at ground locations to the front and sides of the barriers.

2. Flashbulbs, mounted on the test vehicle, were electronically flashed to establish (a) initial vehicle/barrier contact and (b) the application of the vehicle's brakes.

3. Five tape switches, placed at 10 foot intervals, were attached to the ground perpendicular to the path of the impacting vehicle, Figure 4A, Barrier Instrumentation. Flashbulbs were activated sequentially when the tires of the test vehicle rolled over the tape switches. The flashbulb stand was placed in view of all the data cameras and was used to correlate the cameras with the impact events.

Figure 4A, BARRIER INSTRUMENTATION



NOTES:

1. Measurements from Impact Point taken at base of barrier
2. Houston Deflection Potentiometers▼ : Tests 293, 294, located 4' from each end of barrier, 6" down from top; Test 294, located 4' from each end, 2-1/2" up from bottom of barrier.
3. Vehicle Approach Line was the intended path for the left wheels of the test vehicle.
4. 1 ft= 0.305m

Electronic Instrumentation and Data

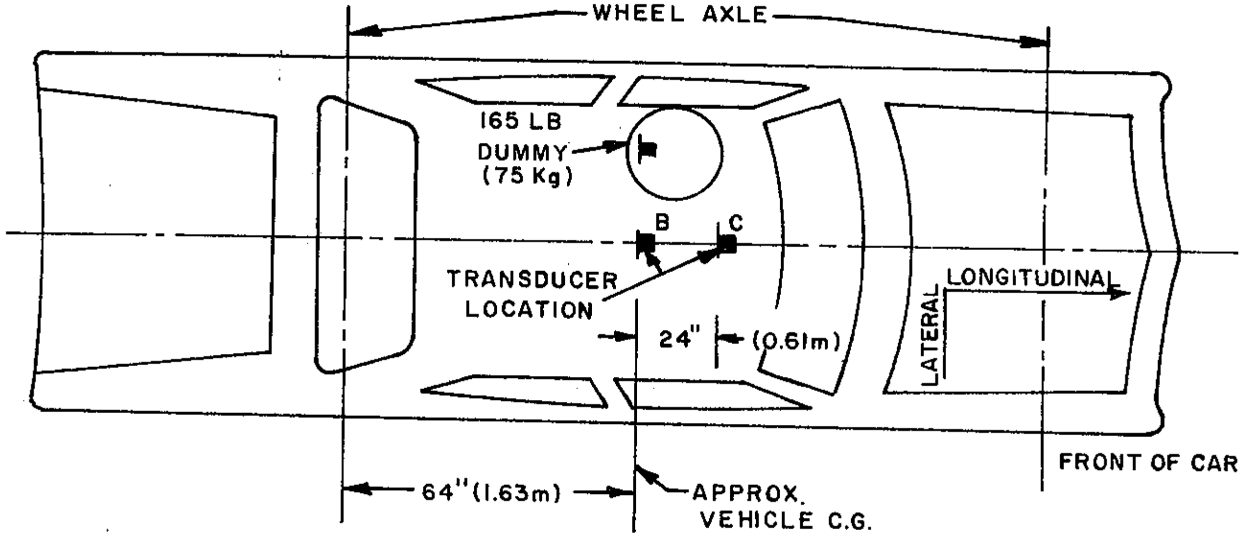
Data from all transducers in the test vehicle (accelerometers and lap belt) were transmitted through a 1000 foot Belden #8776 umbilical cable connecting the vehicle to a fourteen channel Hewlett Packard 3924C magnetic tape recording system. This recording system was mounted in an instrumentation trailer located in the test control area.

Three pressure activated tape switches were attached to the ground at fixed intervals in the vehicle approach path close to the point of barrier impact, Figure 4A. When activated by the test vehicle tires, these switches produced sequential impulses which were recorded with the transducer signals on the tape recorder. A time cycle was also recorded on tape concurrently with the tape switch impulses and the transducer signals. The impact velocity of each vehicle was determined from these tape.switch impulses and timing cycles.

After each test, the tape recorder data was played back through a Visicorder which produced an oscillographic trace (line) on paper for each channel of the tape recorder. Each paper record contained a curve of data representing one transducer, signals from the three tape switches, and the time cycle markings.

Vehicle and Anthropometric Dummy. Figure 5A shows the locations of all transducers mounted in the test vehicles. A total of eight Statham accelerometers, of the unbonded strain gage type, were used for deceleration measurements. Of these, four were mounted, one in the chest and three in the head cavity, in the anthropometric dummy. The other accelerometers were mounted on the floorboard of the test vehicle. Also, one seat belt transducer was installed on the dummy's lap belt for each test.

Figure 5A, VEHICLE INSTRUMENTATION



DATA CHANNEL NO.	TEST NO.	TYPE OF TRANS DUCER	ORIENTATION	LOCATION
1	All	Accelerometer	Longitudinal	A - Dummy's Head
2	All	Accelerometer	Vertical	A - Dummy's Head
3	All	Accelerometer	Lateral	A - Dummy's Head
4	All	Accelerometer	Longitudinal	A - Dummy's Chest
5	291,292	Accelerometer	Lateral	C - Outer Side Of Stl. Box
5	293,294	Accelerometer	Lateral	B - Veh. Floor - C.G.
6	291,292	Accelerometer	Lateral	C - In Polyurethane Foam In Stl. Box
6	293,294	Accelerometer	Longitudinal	B - Veh. Floor - C.G.
7	291,292	Accelerometer	Lateral	B - Veh. Floor - C. G.
7	293,294	Accelerometer	Longitudinal	B - Veh. Floor - C. G.
8	291,292	Accelerometer	Longitudinal	B - Veh. Floor - C. G.
8	293,294	Accelerometer	Lateral	B - Veh. Floor - C. G.
9	All	Seat Belt Force	Tension	A - Dummy's Lap Belt

NOTE:

Location A (for accelerometers) is on the inside back of the head or in the chest cavity of the dummy; Location B is on a steel angle bracket welded to the floor at the vehicle center of gravity;
Location C is a 4"x 4" steel box mounted on the longitudinal axis of the vehicle floor

Longitudinal and lateral vehicle deceleration records for each test are shown in Figures 6A and 7A. Deceleration responses of the anthropometric dummy and the lap belt record for each test are shown in Figures 8A through 12A.

Some of the accelerometer data records contained high frequency spikes. This data was filtered at 100 Hertz with a Krohn-Hite filter to facilitate data reduction. The smoother resultant curves give a good representation of the overall deceleration of the vehicle without significantly altering the amplitude and time values of the deceleration pulse.

Test Barriers. The locations of tape switches used to determine impact velocity and to correlate high speed movies and the barrier instrumentation for each test are shown in Figure 4A.

Houston Deflection Potentiometers were positioned at the back side, 6 inches down from the top of the barrier and 6 feet on either side of the point of impact for Test 293. For Test 294 one additional potentiometer was placed 2 1/2 inches up from the base of the barrier on either side of the point of impact. These potentiometers monitored lateral barrier deflection during impact, Figure 13A.

Figure 6A, VEHICLE DECELERATION VS TIME

LONGITUDINAL

UNANCHORED PRECAST SAFETY SHAPED CONCRETE BARRIERS

TEST	LENGTH OF SEGMENTS FT.	DESIGN GAP AT PINNED JOINTS IN.
291/292	12.5	0
293	20	2.75
294		0

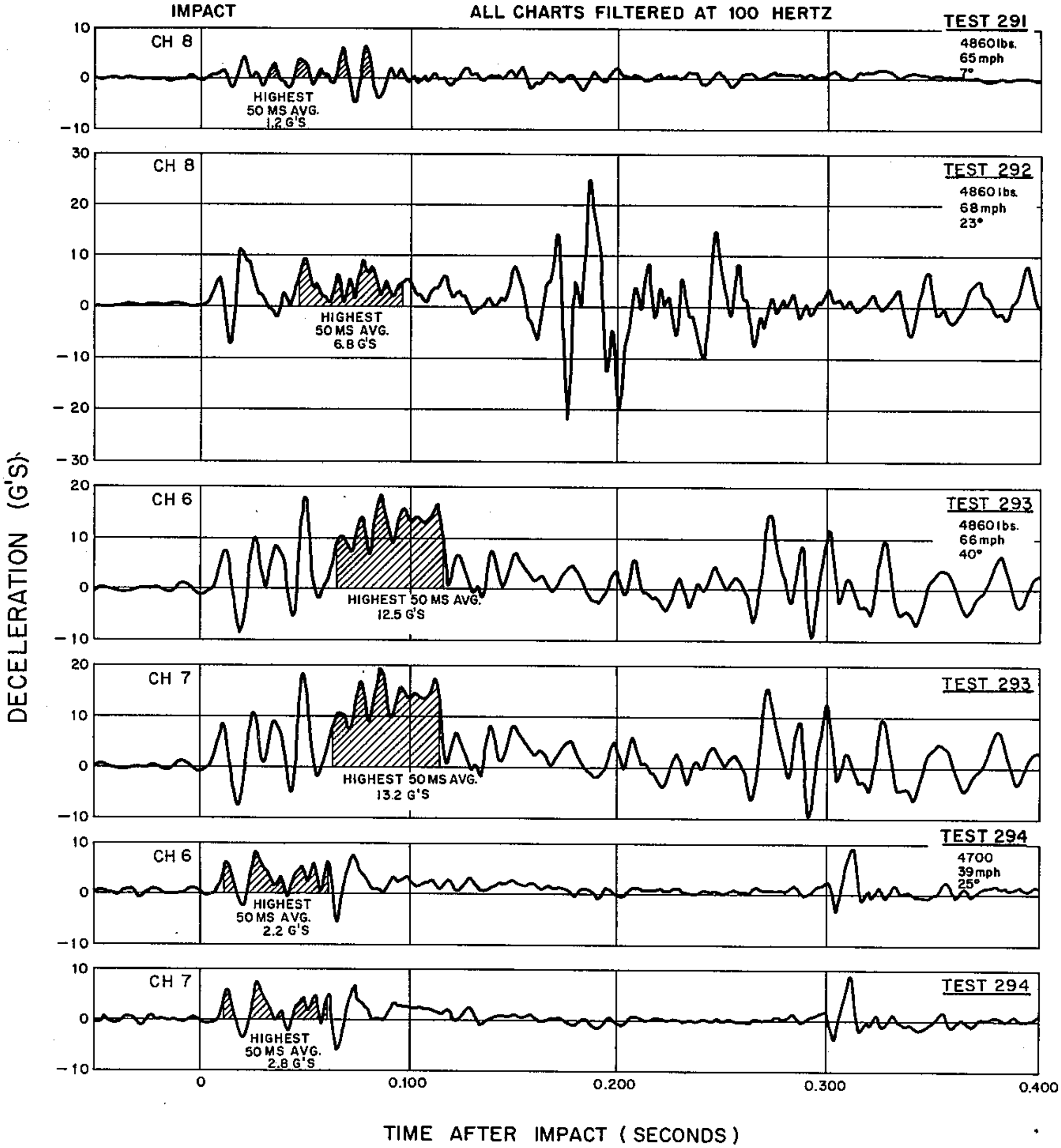


Figure 7A, VEHICLE DECELERATION VS TIME

LATERAL

UNANCHORED PRECAST SAFETY SHAPED CONCRETE BARRIERS

TEST	LENGTH OF SEGMENTS FT.	DESIGN GAP AT PINNED JOINTS IN.
291/292	12.5	0
293	20	2.75
294		0

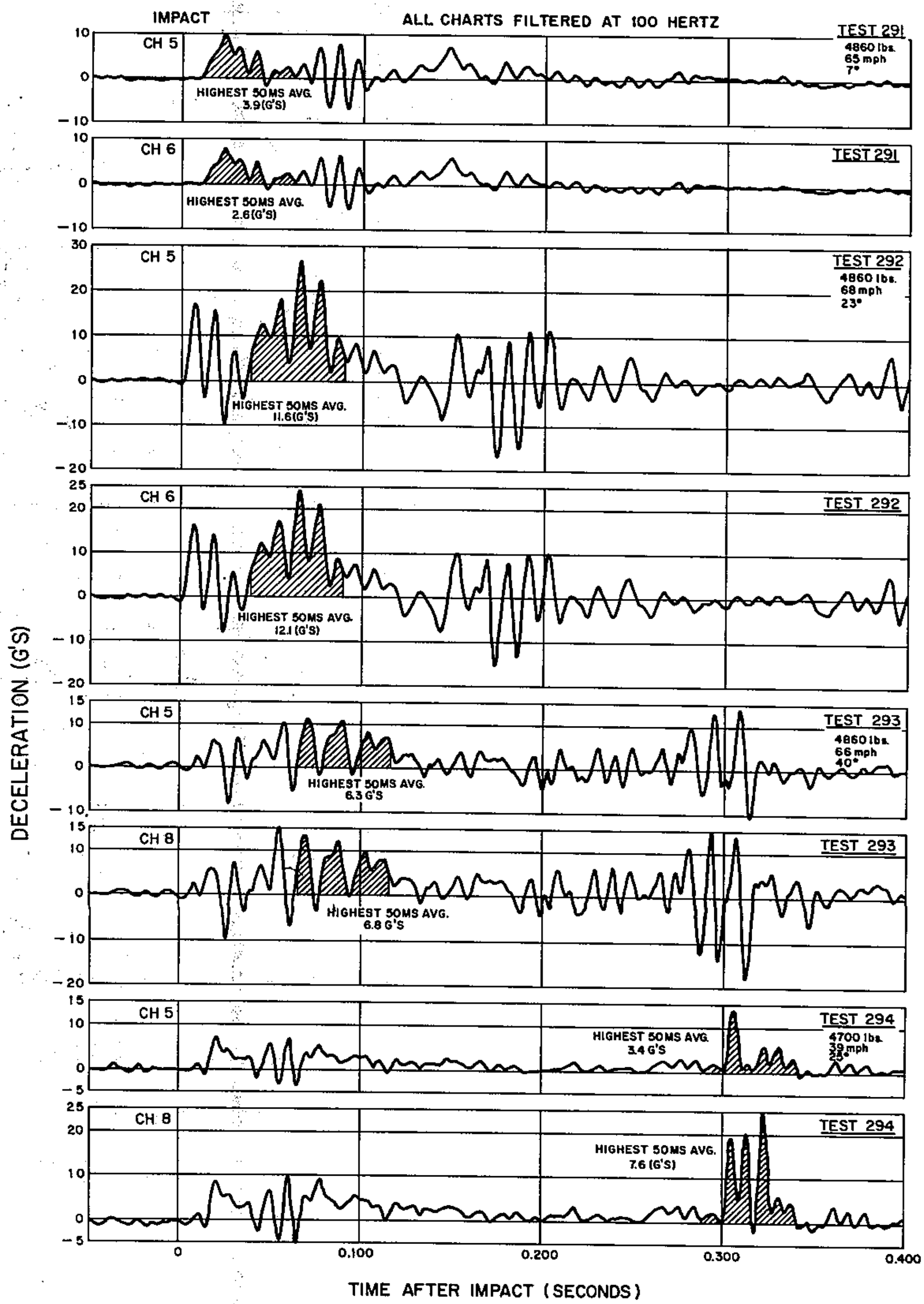


Figure 8A, DUMMY DECELERATION VS TIME

TEST 291, 4860 lb. VEHICLE, 65 MPH, 7°, LAP BELT

12.5 FT. LONG SEGMENTS, NO DESIGN GAP AT PINNED JOINTS

UNANCHORED PRECAST SAFETY SHAPED CONCRETE BARRIER

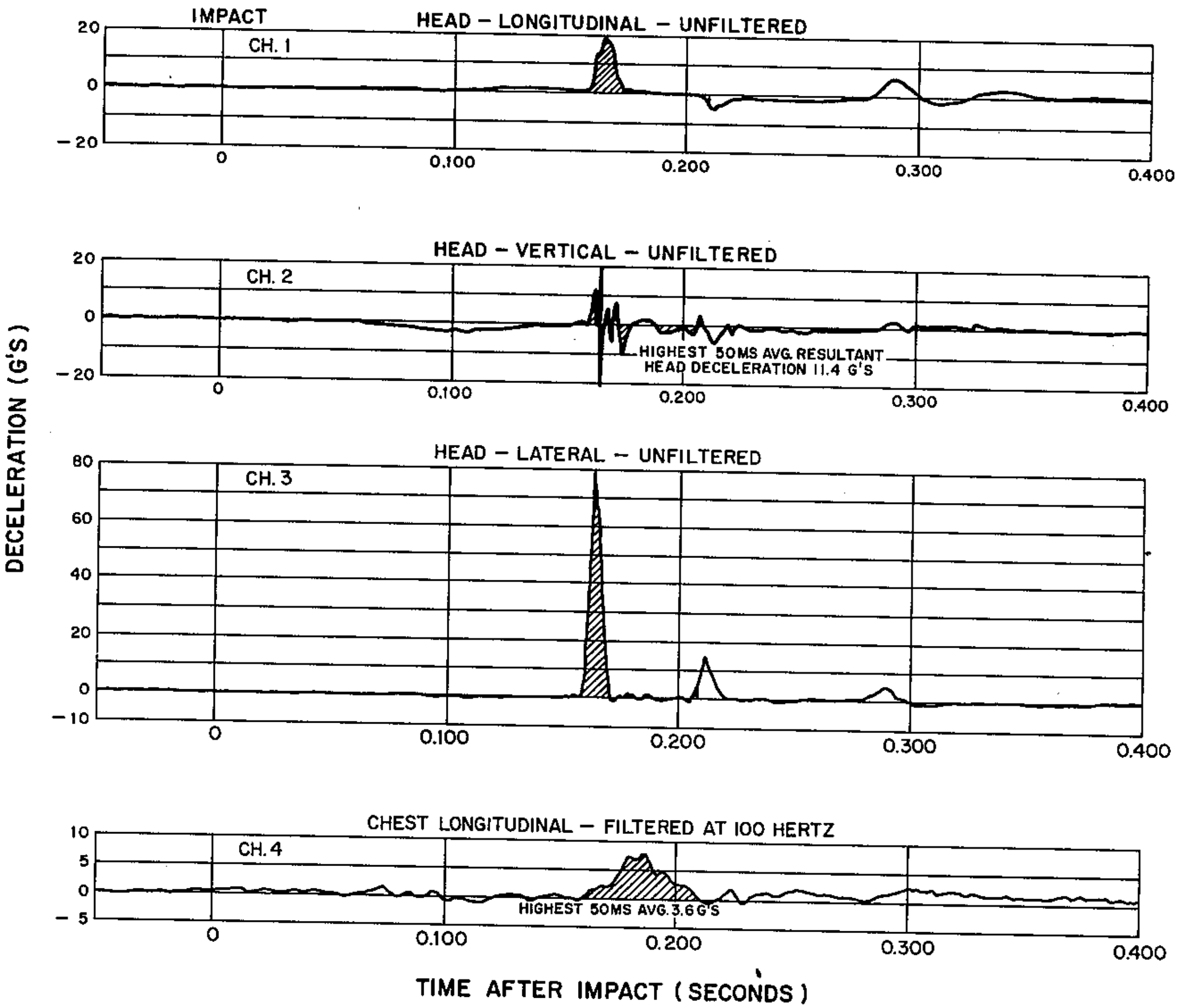


Figure 9A, DUMMY DECELERATION VS TIME

TEST 292, 4860 lb. VEHICLE, 68 MPH, 23°, LAP BELT

12.5 FT. LONG SEGMENTS, NO DESIGN GAP AT PINNED JOINTS

UNANCHORED PRECAST SAFETY SHAPED CONCRETE BARRIER

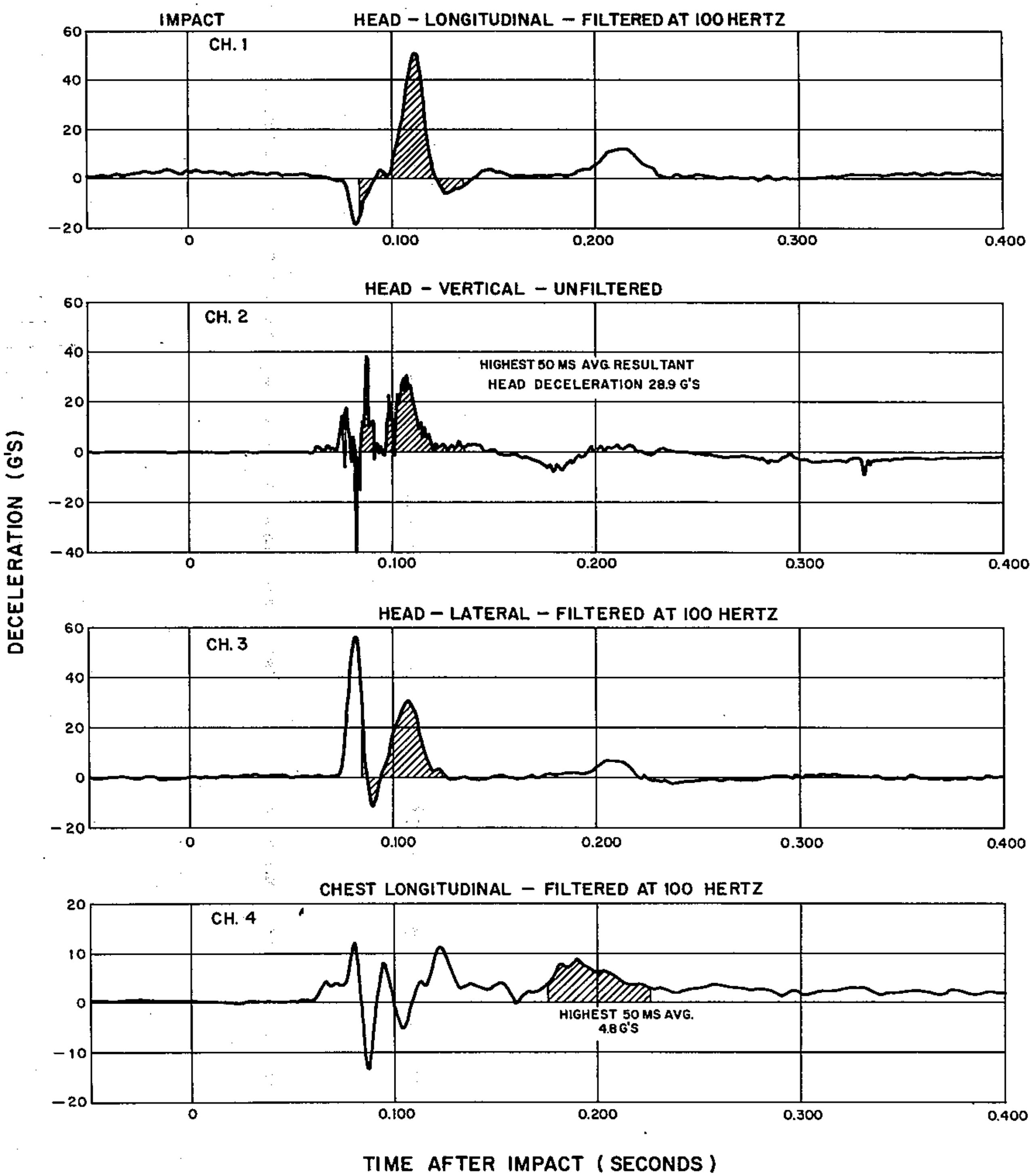


Figure 10A, DUMMY DECELERATION VS TIME

TEST 293, 4860 lb. VEHICLE, 66 MPH, 40°, LAP BELT

20 FT. LONG SEGMENTS, DESIGN GAP AT PINNED JOINTS = 2.75 IN.

UNANCHORED PRECAST SAFETY SHAPED CONCRETE BARRIER

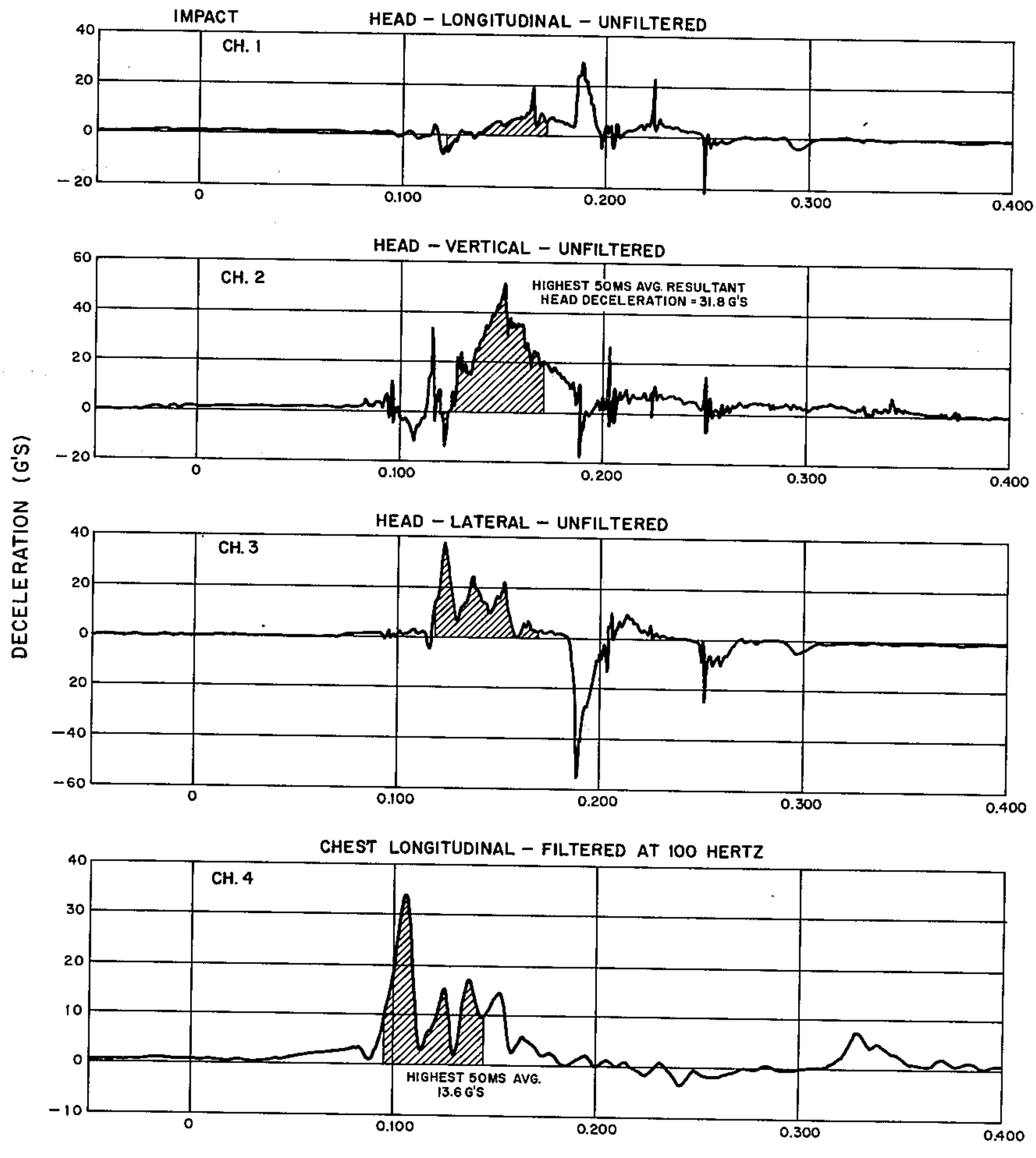


Figure 11A, DUMMY DECELERATION VS TIME

TEST 294, 4700lb. VEHICLE, 39 MPH, 25° LAP BELT

20 FT. LONG SEGMENTS, NO DESIGN GAP AT PINNED JOINTS

UNANCHORED PRECAST SAFETY SHAPED CONCRETE BARRIER

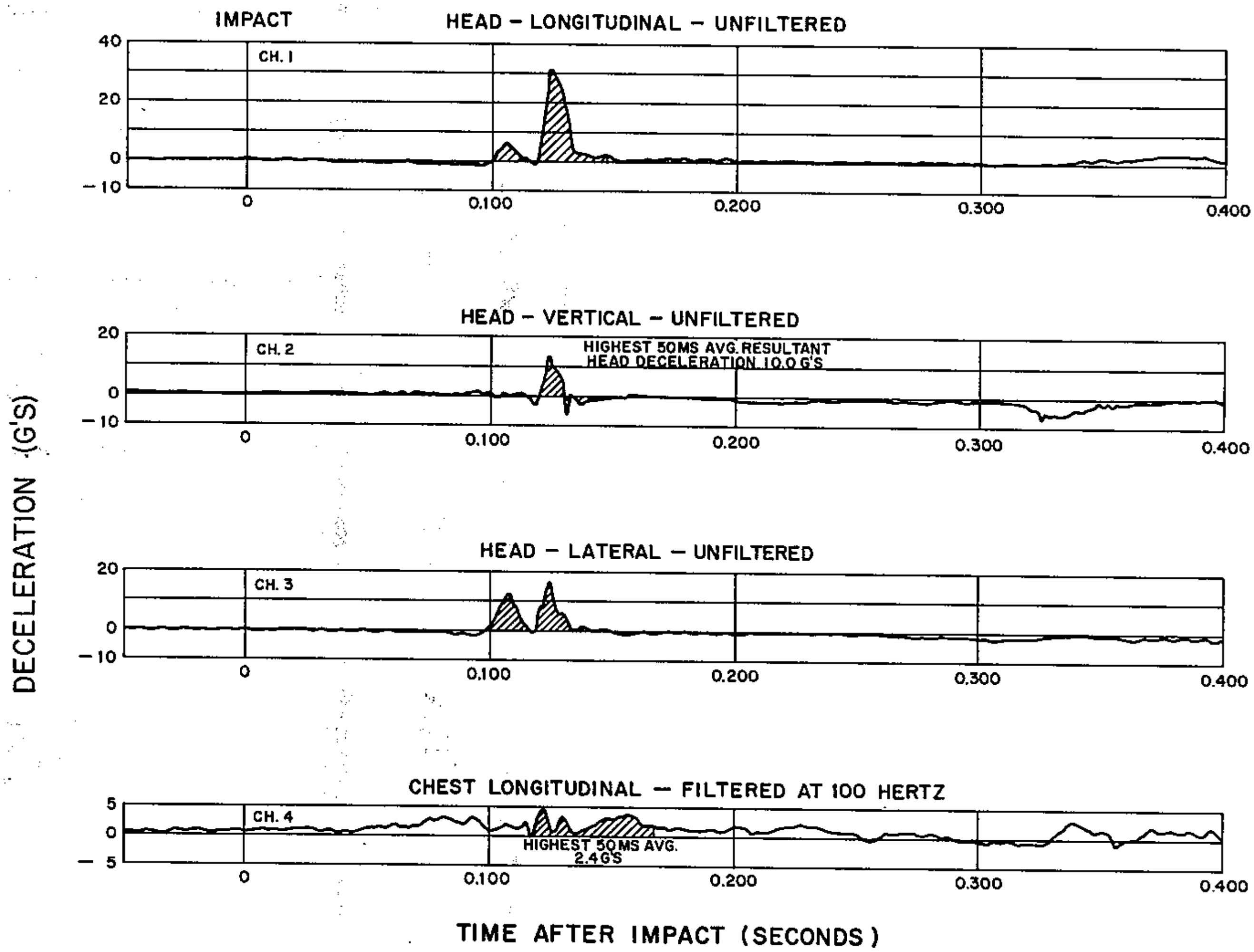


Figure 12A, DUMMY LAP BELT LOAD VS. TIME

UNANCHORED PRECAST SAFETY SHAPED CONCRETE BARRIERS

TEST	LENGTH OF SEGMENTS, FT.	DESIGN GAP AT PINNED JOINTS, IN.
291/292	12.5	0
293	20	2.75
294		0

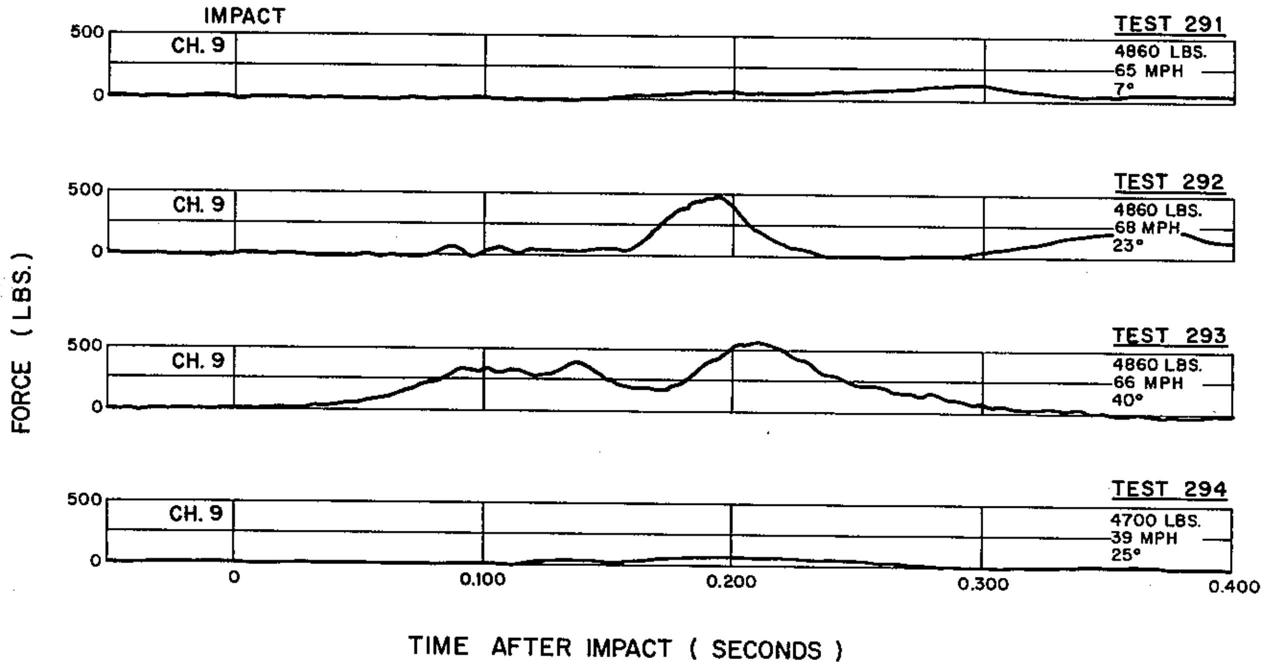
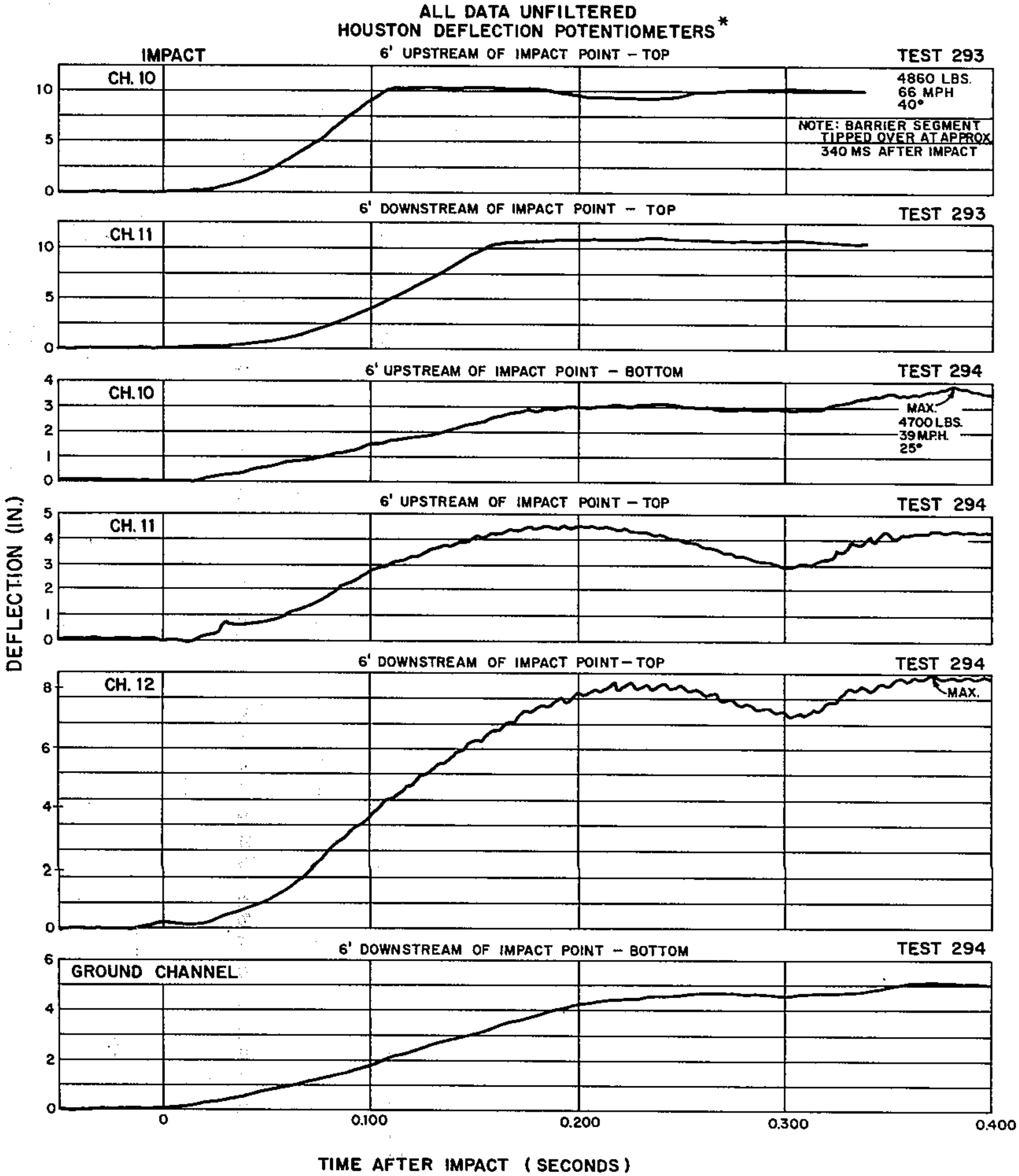


Figure 13A, BARRIER DEFLECTION VS TIME

UNANCHORED PRECAST SAFETY SHAPED CONCRETE BARRIERS

TEST	LENGTH OF SEGMENTS, FT.	DESIGN GAP AT PINNED JOINTS, IN.
293	20	2.75
294		0



*TOP = 6" DOWN FROM TOP OF BARRIER.
BOTTOM = 2 1/2" UP FROM BOTTOM OF BARRIER.

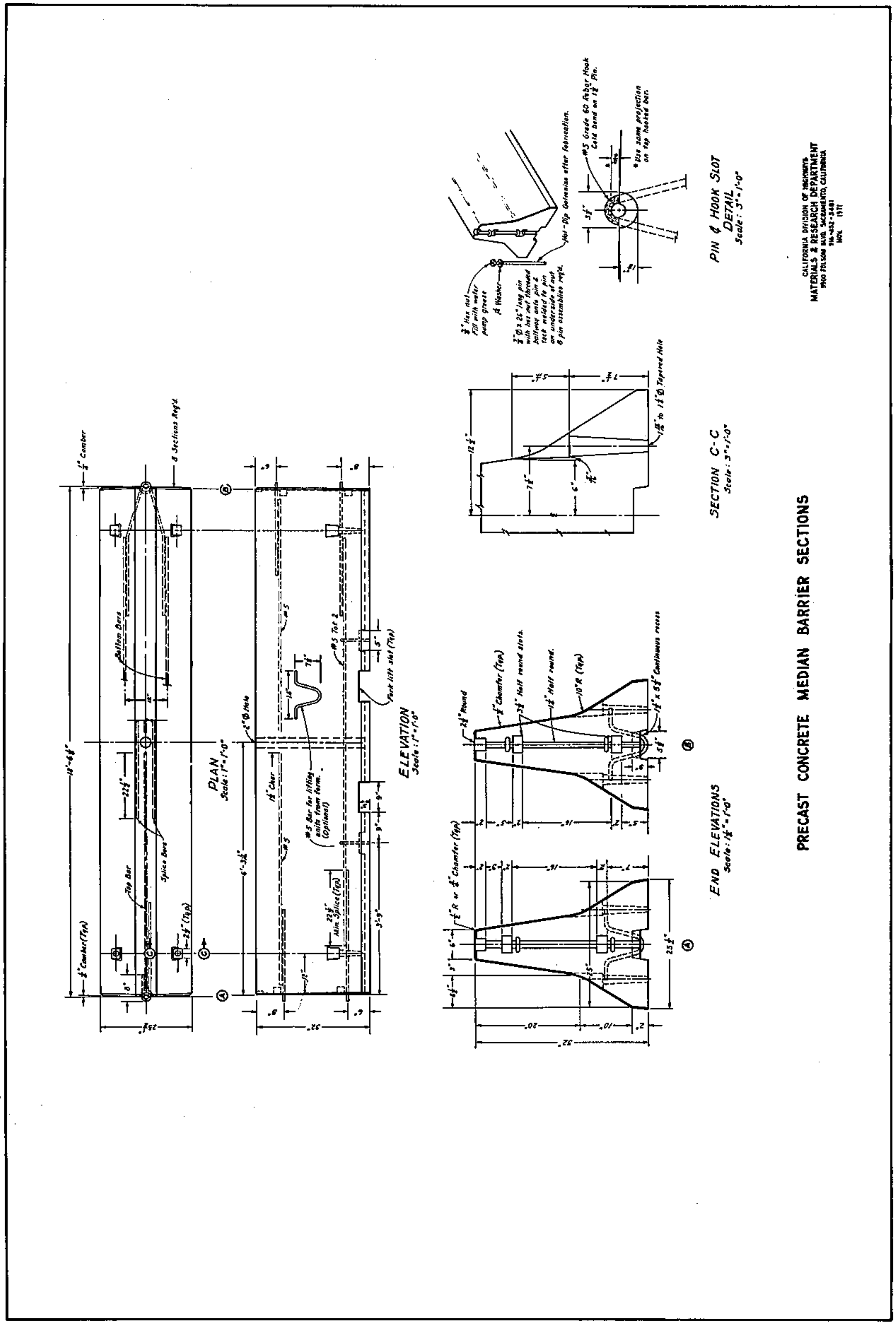


Figure 14A, Barrier Plan, Tests 291 and 292

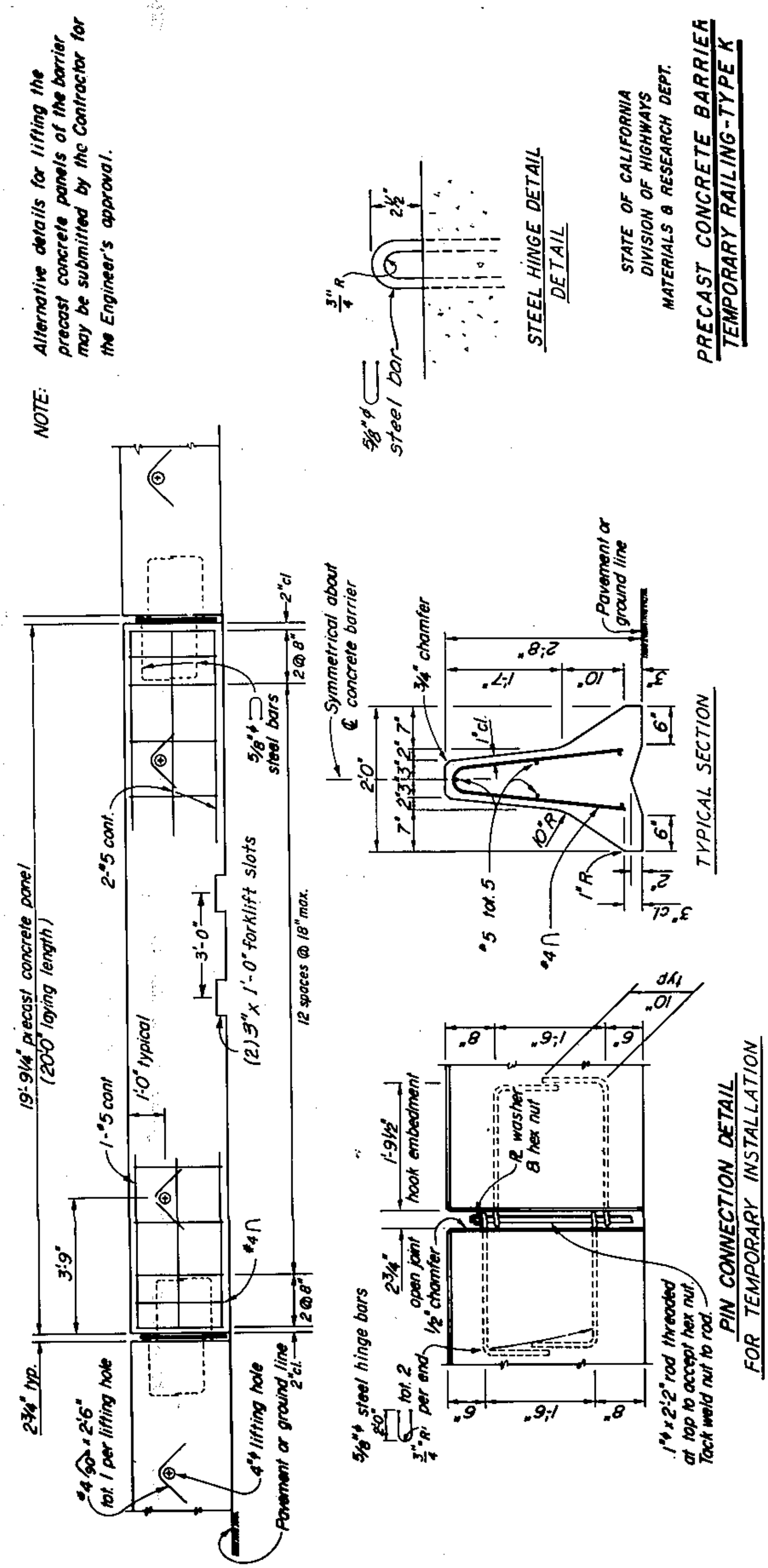


Figure 15A, Barrier Plan, Test 293

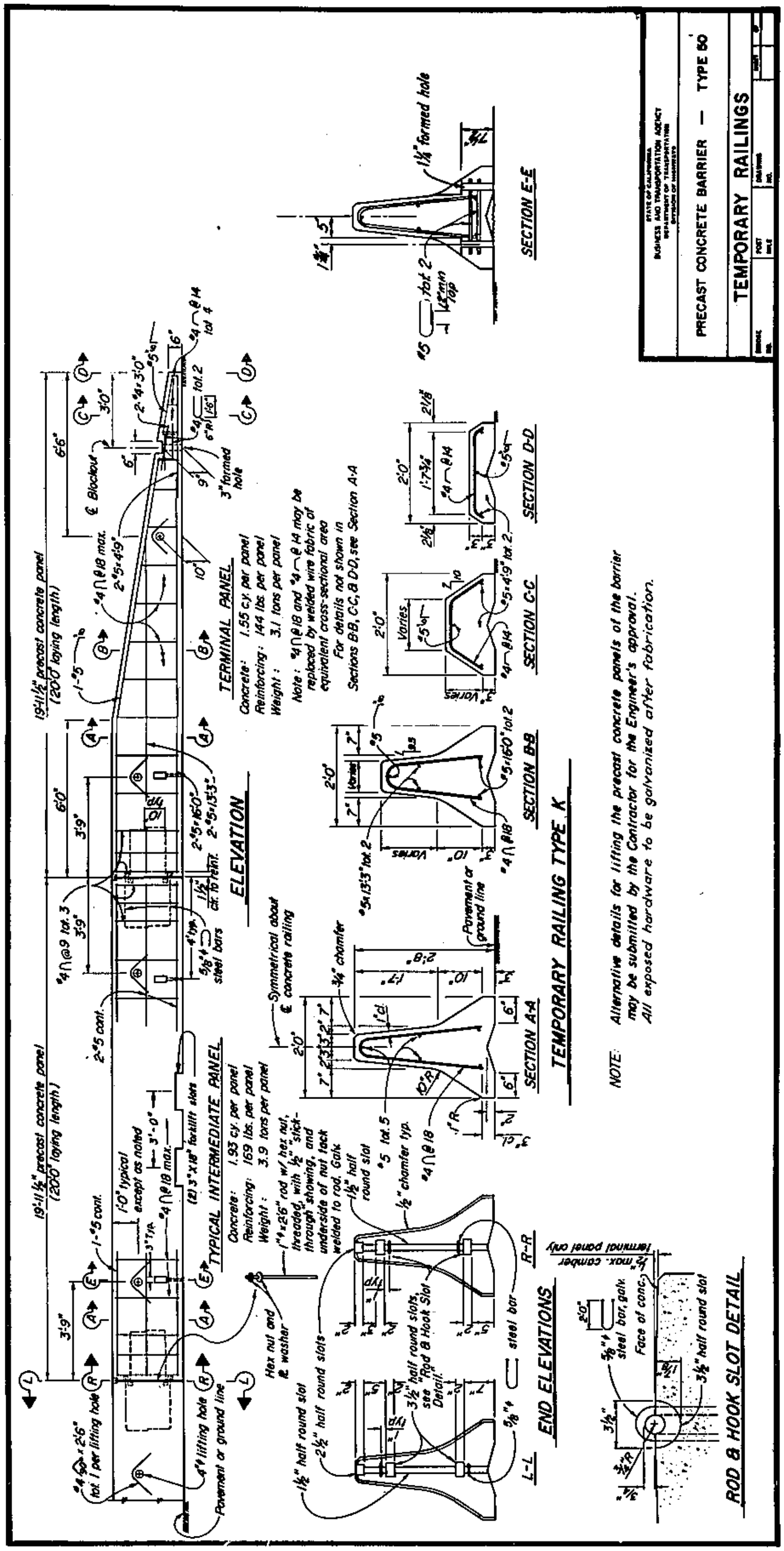


Figure 16A, Barrier Plan, Test 294

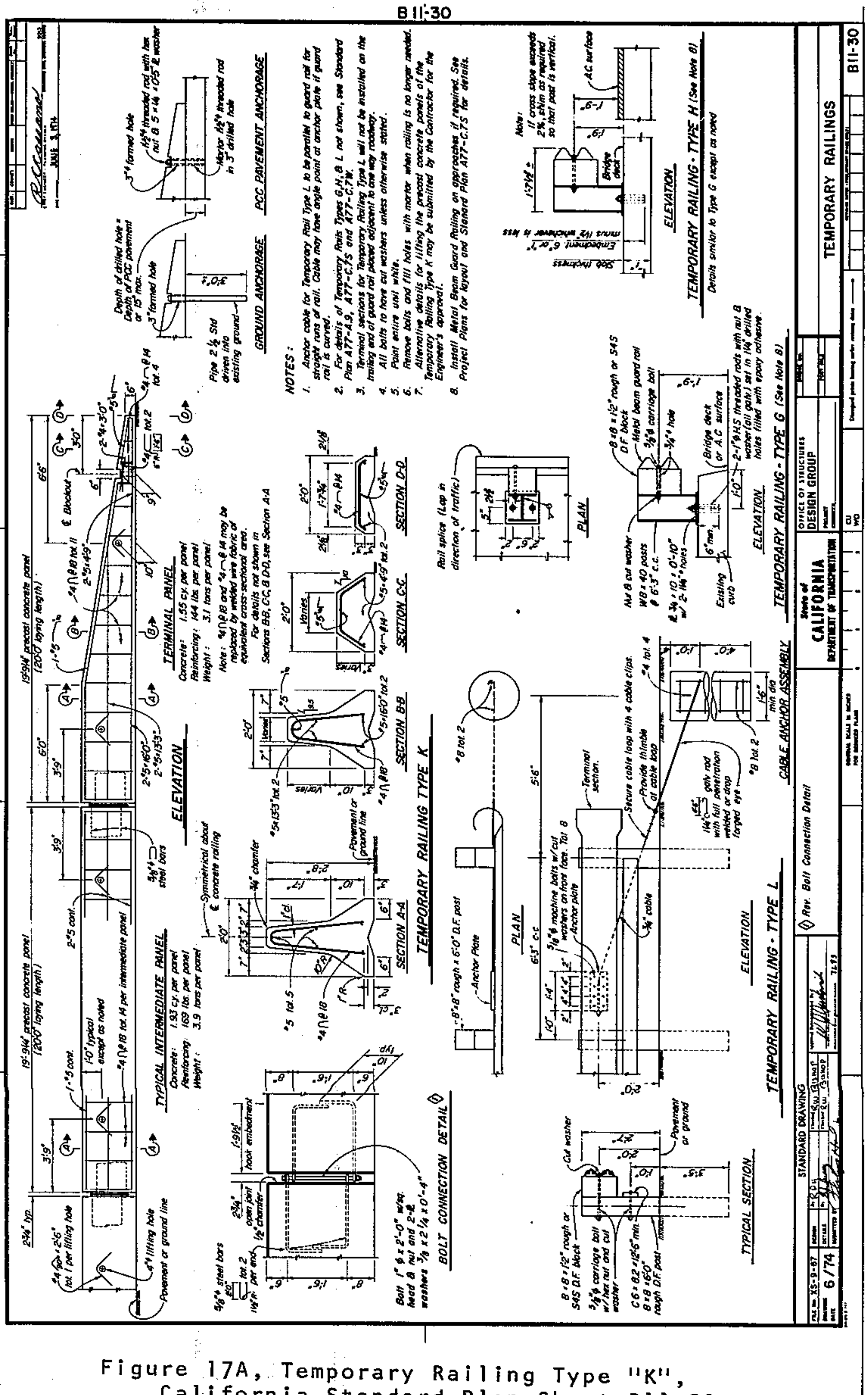


Figure 17A, Temporary Railing Type "K",
California Standard Plan Sheet B11-30

Figure 18A, BARRIER MATERIAL SAMPLE TESTS

TEST NO — DATE OF CRASH TEST	CONCRETE			CONNECTING RODS			HINGE BARS		
	DATE OF STRENGTH TEST	DAYS AFTER CASTING	COMP. STRENGTH PSI	TENSILE YIELD STRENGTH PSI	TENSILE ULTIMATE STRENGTH PSI	ELONG-ATION %	TENSILE YIELD STRENGTH PSI	TENSILE ULTIMATE STRENGTH PSI	ELONG-ATION %
291 & 292 — 3-8-72	3-13-72	28	5610	7/8" DIA. STL. ROD			# 5 REBAR		
	3-14-72	↓	5500	—	NO TESTS	—	51,600	77,600	18
	3-15-72		5670						
	3-17-72		5860						
	3-21-72		5540						
	3-22-72		5960						
	3-23-72		5270						
	3-24-72		5680						
	3-27-72		5320						
293 — 5-10-73	4-19-73	7	2820	1" DIA. STL. ROD			5/8" DIA BOLT		
	4-26-73	14	4000	59,500	92,300	21	36,500	57,400	23
	5-10-73	28	5160						
	5-10-73	28	3770						
	5-10-73	28	3570						
294 — 11-20-74	10-2-74	15	3500	1" DIA. STL. ROD			5/8" DIA ROUND BAR		
	10-15-74	28	4280	51,200	95,000	26	40,500	62,800	28
	11-20-74	64	5175						

NOTES:
1. All concrete was a 6 sack mix.
2. Concrete for Tests 291, 292 was steam cured.
3. Values for concrete & hinge bars were the average of two samples.
4. The hinge bars Tests 291, 292 complied with ASTM A-615, Grade 40 requirements
5. The hinge bars for Tests 293, 294 complied with ASTM A-36 requirements.
6. The connecting rods for Tests 291, 292 were req'd to comply with ASTM A-306 Grade 80

Field Experience

In the Fall of 1975 several Caltrans construction personnel were contacted for their comments on the field performance of temporary precast CMB designs they had used on construction jobs. Following are summaries of their comments:

1. Senior Bridge Construction Engineer, District 07, Los Angeles.

Most precast CMB now used is the chained type although some Type K Temporary Railing with pinned ends is used. Segments are 20 foot long. He thinks the chained type is preferable because there is no gap at the joints, and they are easier to set up. With the pinned ends, more work is required to align the segments to insert the steel rods. Most of the barrier is set on even ground. He says the barrier has performed very well. He does not know of any segments which have tipped over. He thought the maximum barrier movement from impacts was about 1 to 1-1/2 feet. They have used this barrier on one heavily traveled freeway where 51 bridges were involved, thus indicating considerable exposure time for the barrier. He expressed some concern for situations where the barrier segments are placed directly in front of vertical drop-offs, and feels they may have just been lucky that no barrier segments were knocked over the edge.

2. Resident Engineer, and Bridge Engineer, District 07, Los Angeles.

They required the contractor to provide precast CMB before allowing men to work within 6 feet of the traveled way during daytime hours. This barrier was the chained type using 20 foot barrier lengths. Initially the contractor did not want to chain the segments, then wanted to use only one loop. The Caltrans personnel required the contractor to use two loops of chains. The barrier segments were butted together, the chain was snug but not stretched in any way. They have used a few segments of Type K Temporary Railing with pinned ends, but evidently they did not realize there should be a nut on the bottom of the steel rod. They flare the barrier alignment at the ends and use the tapered terminal segment. All barrier segments were usually on even ground. The segments were moved occasionally with a loader or more often with an H-3 hydro crane with a capacity of about 20 kips on a vertical lift. They did not use a fork lift; there were no fork lift slots in the barrier. They preferred the longer 20 foot segments over something shorter, provided moving equipment was available. Accident experience was good; barrier movement had not been over 1-2 inches. Most of the barrier had the same alignment as when it was installed. In the most severe accident they could remember, scuff marks appeared high on the barrier and car parts from a yellow Mustang were left at the accident scene, but they did not remember any barrier movement. They had no other accident details. They felt the barrier segments in place were doing the job quite well and were much better than non-concrete temporary barriers used previously.

3. <u>Construction Engineer, Field Area Supervisor, District 07, Los Angeles.</u>

He mentioned one job using 150 - 10 foot long segments of pinned end precast CMB. They were used to permit daytime work in the median on drainage improvements. The steel rod used was actually a long bolt with a nut on the bottom. Evidently the design used was similar to our standard Type K Temporary Railing (several persons referred to the <u>chained</u> end barrier design as a Type K Temporary Railing) with about a 3 inch gap between ends of segments. There had been some sideswipes of the barrier with barrier movement of only a few inches. He said temporary CMB is usually placed on even ground. The barrier units had no scuppers on the bottom, hence fork lifts were not used for handling. Eyebolts cast into the top of the barrier were used for lifting. He felt the 10 foot segments were preferable to the 20 foot segments for ease of hauling.

4. Construction, Plan and Specification Reviewer, District 07, Los Angeles.

He thought that in general the current standard Type K Temporary Railing design with pinned ends and nut on the bottom is used, although some left over chain type CMB segments are still used. He thought there was no barrier movement when impacts occurred except where segments were not tied together or the end segment was hit. He thought a 12 foot maximum length was preferable to a 20 foot length so that the CMB segments could be hauled cross-wise on a truck. It was his understanding that the CMB segments were quite durable, and were often used on 3 to 4 jobs or more.

He likes the eyebolt detail for lifting CMB segments. He thought the units were handled with a truck crane for transportation from one job to another, but moved with a forklift around one given jobsite. He thought uneven ground was rarely a problem. One suggestion he made was to give new designations to different precast CMB designs. By referring to both the chain type and pinned end designs as Type K Temporary Railing, confusion was created, and disputes with the contractor resulted when he wanted to use older designs on a job.

5. Resident Engineer, District 03, Sacramento.

He has used mostly pinned end CMB units without a nut on the bottom of the pin, although he said most of the units under overcrossings were the chained type. All were 20 foot segments, mostly placed on even ground, usually on paving. The steel rod used was a #8 rebar and wooden wedges were used to take slack out of the joints. The units supplied by the contractor had pin loops of steel cable cast in the barrier ends. The size of the cable and the loops varied so he felt the strength of the loops would be variable. He said they used two wraps of 3/8 inch diameter cable instead of chain to connect the chain type CMB units. Wedges were also used at the joints on these units to take up the slack. The CMB units on this job had scuppers, and large forklifts were sometimes used to move them. Truck mounted hydro cranes with 20,000 lb working load capacities were also used. Some units had lifting eyebolts in the top; some were moved using the chain holes at the ends of the CMB units. He said some of the units were in bad condition. Several had portions broken off the top, and there was a typical spalling at the scuppers. Four units were rejected because of double "X" cracks in the middle. He felt the damage was due both to poor handling, dropping, etc. and to dropping of falsework members, etc. on top of the units.

Two accidents which happened on the job were described. In one, a car got into the median, went down the slope between two bridges, and struck some CMB units from the backside at about a 90° angle. These CMB units were "chained" together. They did not tip over, but three segments moved. Maximum deflection of the units was about 8 to 9 feet. The impacting vehicle was a Pinto.

The other accident occurred on a bridge deck. The vehicle hit CMB units on the right side of the roadway, then crossed the roadway and hit units on the other side at a large angle close to 90°. The end of one unit sheared off and about six units showed signs of movement. He felt this demonstrated the effectiveness of the wedges at the joints in carrying loads across the joints. No one saw the accident; there was no accident report; hence, they do not know what type of truck or car was involved. This length of CMB was within six inches of the edge of deck. Dowels had been placed in the deck and the CMB units tied down to prevent the units from being knocked over the edge. It was felt this tie-down arrangement was effective.

6. <u>Construction Staff Meeting, District 07, Los Angeles.</u>

After the above information had been gathered, the subject was raised at a District 07 Construction Staff Meeting of senior and supervising engineers. The consensus at this meeting was that the CMB units now in use perform well; the chain connection detail is preferred; the pin connected units should not be discarded because they work satisfactorily and it would be a hardship on contractors who have a large supply of this type of unit; they could think of no specific improvements needed in the design; the units have been hit many times; none have tipped over and the maximum barrier deflection has been about 12 to 18 inches. The exposed approach end condition was considered a problem. They now often use Fitch Inertial Sand Barrels at these ends.